1966

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MORACHAN, Yedappalli Bella, 1924-
CUMULATIVE EFFECTS OF ORGANIC RESIDUE APPLICATION ON PHYSICAL AND CHEMICAL PROPERTIES OF MARSHALL SILTY CLAY LOAM.

Iowa State University of Science and Technology, Ph.D., 1966
Agriculture, plant culture

CUMULATIVE EFFECTS OF ORGANIC RESIDUE APPLICATION ON PHYSICAL AND CHEMICAL PROPERTIES OF MARSHALL SILTY CLAY LOAM

by

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A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
DOCTOR OF PHILOSOPHY

Major Subject: Soil Management

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

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Signature was redacted for privacy.

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Of Science and Technology
Ames, Iowa

1966

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I. INTRODUCTION

The organic matter of soils is commonly considered to have two functions that bear on soil productivity and plant growth. One is essentially physical and consists in maintaining soil tilth, holding moisture and retaining plant nutrients either in an exchangeable form or combined in a less available form as part of the humus body.

The other function occurs during the decomposition process and results in the liberation of combined nitrogen and other nutrients. The rate of decomposition is largely determined by such conditions as temperature, moisture and aeration which regulate biological activity.

Organic matter is said to play a key role in the formation of soil structure. While nutrients, water and air are essential for plant growth, the air and water relationships are dependent upon structure. The organic matter besides producing gelatinous material that surround and hold soil particles together through cementation, serves as a source of food and stimuli for living bacteria and fungi (and possibly actinomycetes) that bind soil particles together. The size and shape of the individual aggregates, their arrangement and stability are all affected by organic matter.

In spite of the importance of the subject of aggregation to agriculture, and the excellent work that has been done, mostly by soil microbiologists, our knowledge of the processes by which soil particles are caused to aggregate and the forces which keep them aggregated is limited and often apparently contradictory (87). Sufficient information is not available on aggregate size distribution, their strength and stability.

The role of organic matter in aggregation and the resulting physical and chemical characteristics is widely recognized. But little information is available when large amounts of organic material are added continuously over a long period under field conditions. The objective of the present investigation is to determine the cumulative effects of different amounts and time of application of residues over a period of years on the physical and chemical properties of soil.

In this thesis are reported the results of a study made on an experiment initiated by Dr. W. V. Bartholomew in 1953 at the Soil Conservation Experimental Farm, Clarinda, Iowa, wherein systematic incorporation of plant residues have been made since that time.

II. REVIEW OF LITERATURE

The total organic matter of soils consists of living organisms of various types, together with their decaying residues. The bulk of the organic matter falls within the category of decaying residues and is derived directly or indirectly from plant tissue.

Although the general chemistry of the different types of plant material that ultimately become the organic fraction of soil is similar, there may be considerable variation in the properties of several constituents. Soil organic matter is a product of its environment no less than the inorganic fraction. Reviews of the properties of soil organic matter have been published by Norman (86), Bremner (17,18) and Broadbent (19).

The composition and formation of organic matter have been studied for a long time and an enormous literature is available on these aspects. But our knowledge on the cumulative effects of organic matter on physical and chemical properties of soil and crop growth is limited. The available literature is reviewed here.

The review is divided into two parts in the following order:

A. Effect of organic matter on plant growth and yield.

B. Effect of organic matter on physical and chemical characteristics of soil.

A. Effect of organic matter on plant growth and yield

The organic fraction of soils may affect plant growth indirectly through its properties of binding soil particles together into structural units and holding cations in exchangeable form. On decomposition, soil organic matter releases nitrogen, phosphorus and sulphur in forms available to plants. Other indirect effects may be attributed to the carbon dioxide released during organic matter decomposition.

The extent to which soil organic matter *per se* affects plant growth is a question of long standing. Whitney (131) proposed what might be called the "organic toxin" theory of soil fertility. Although Whitney's hypothesis about plant nutrients was found to be incorrect, recent evidence supports the organic toxin idea in a limited way. Work on this subject was summarized by Bonner (14). Although the production of organic plant toxins by microorganisms acting on plant residues or soil organic matter remains to be demonstrated, the existence of such toxins is likely in view of recent developments of knowledge regarding production of antibiotic substances by microorganisms.

Antibiotic substances produced in soils by microorganisms may affect plant growth in various ways. A brief review on this subject was published by Evans and Gottlieb (37). Recently, McCalla *et al*. (77) reported that under special conditions, such as in wet cool spring seasons with a heavy layer of mulch at the surface of soil, some microorganisms may produce phytotoxic substances affecting plant growth.

Various claims of special beneficial effects of soil organic matter have been advanced from time to time. Bottomley (15) found plants in water cultures grew better when an extract of "bacterized peat" was added and gave the name "auximones" for these substances. Later, the work of Clark and Roller (27) clearly indicated that the favorable effects of organic matter were associated with microbial activity and not with organic matter *per se*. More recent evidences by Schmidt (112) and Audus (5) suggest that the unexplained favorable effect of organic matter and microorganisms may have resulted from vitamins and hormones.

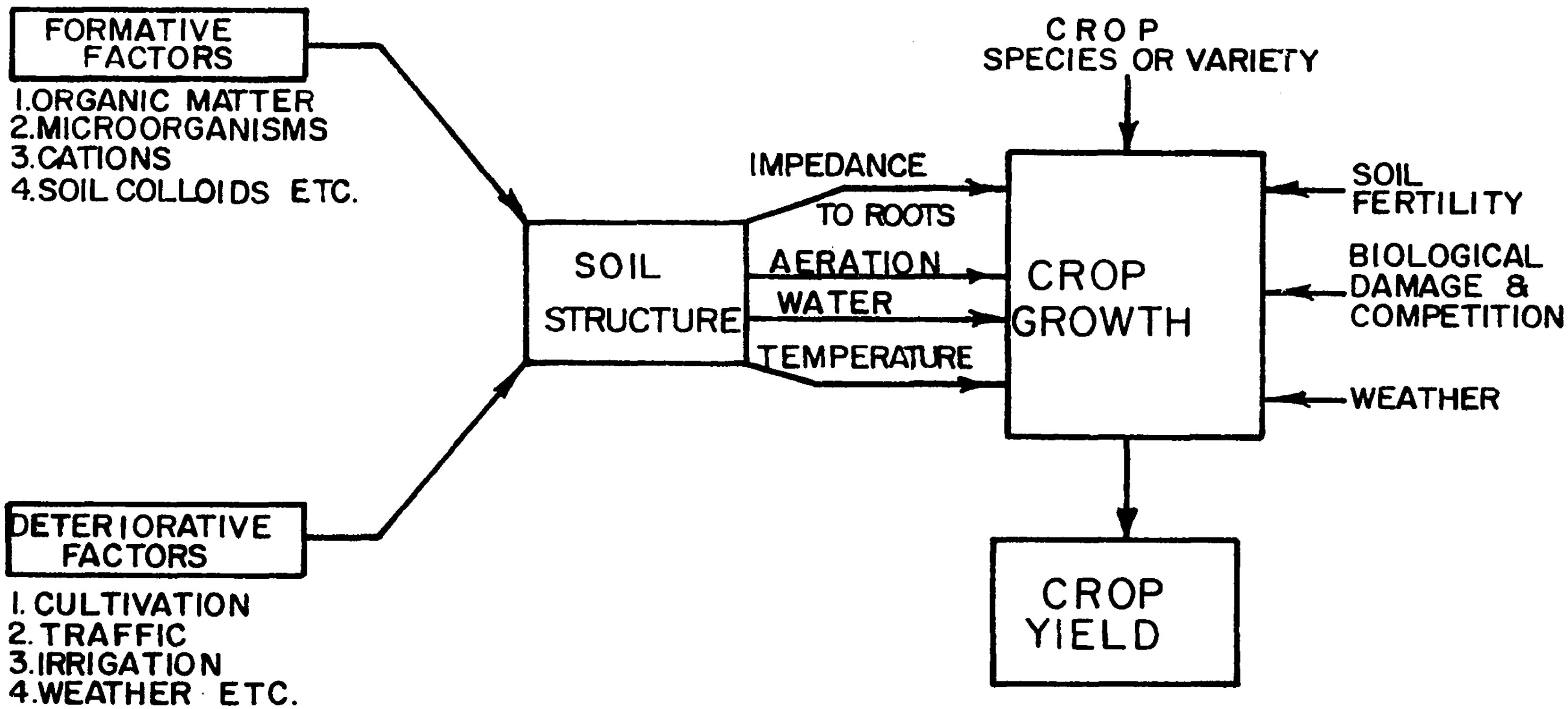
The indirect effect of organic matter on plant growth is mostly due to its effect on soil structure and the resulting characteristics. Soil structure may affect plant growth in a variety of ways, some direct and some indirect. By offering mechanical impedance, structure affects plant growth in the emergence of seedlings in crusted soils, in restriction of root development in hard surface soils and in the failure of roots to expand normally in compacted or fine-textured zones below the soil surface. Indirectly, soil structure may have important effects on plants through its influence on air, water and temperature relationships of soils.

In evaluating the effects of structure on plant growth, comparisons are hard to make because of wide variation in methods of expressing aggregate analysis data. However, there is much evidence that the values measured by aggregate analysis may not be primary factors in increasing yield but are only associated with some of the other factors such as more root nitrogen, more available water due to infiltration, etc. This is borne out by data of several papers. Figure 1 illustrates the major factors contributing to soil structure and plant growth as adapted from the review of Kemper and Koch (60).

Strickling (119) found no apparent relationship between soil aggregation and crop yields. Swanson and Jacobson (120) found large yield difference due to various treatments of cultivation and weed killers, but had no physical measurements which could account for the difference. They suggested crust as a major cause for yield difference but presented no data. Taylor and Martin (121) found increased yields of corn, oats, tomatoes and carrots with soil conditioners but increased moisture absorption may have been part of the cause as shown by decreased runoff and erosion. Rynasiewicz (111), using >0.5 mm. aggregates as a measure of water stability, found an almost linear correlation between aggregation and yield of onions. The correlation coefficient was 0.996. The yields during the period 1937 to 1942 were correlated with the water stability of aggregates measured in 1943. Van Bavel and Schaller (125) found a highly significant positive correlation between aggregates and corn yields. There was no data given to show that the difference was not due to associated

Figure 1. Factors contributing to soil structure and crop growth.

FACTORS CONTRIBUTING TO SOIL STRUCTURE AND CROP GROWTH



factors. In all these cases, the inability of the experimenters to vary soil structure without varying the associated factors such as soil fertility and organic matter has been pointed out.

Dutt (34) reported that puddling decreased yield by about 5 percent but did not change the percent aggregates >0.9 mm. in size. Page and Willard (88) found that there was no clearcut and consistent relationship between yield and aggregation. Hagin (45) using aggregate size analysis as an indicator of soil structure found that coarsely aggregated soil produced greater plant growth than finely aggregated soil.

In clay soils where aeration was considered a problem, DeBoodt and DeLeenheer (29) and Hubbel and Glen Staten (50) found that pore space at the wilting point and yield were correlated at the 5 percent level of significance. Baver and Farnsworth (8) working with sugar beets found that yield increased with increasing non-capillary pore space (pore space at field capacity) up to about a non-capillary pore space of 8 to 10 percent. Above the values of 8 to 10 percent some factors other than aeration seemed to be limiting growth. Yoder (132) obtained the highest yields of seed cotton on artificially prepared seed-beds containing 3 to 6 mm. aggregates. The non-capillary porosity of the soil was about 30 percent. Kvasnikov (quoted by Sokolovsky (116)) found that millet and spring wheat gave the best yields when the aggregates in soil were 1 to 3 mm. in size. Only about one-fourth as much grain was produced where the soil aggregates were <0.5 mm.

DeBoodt, Englehorn and Kirkham (31) reported that although corn yields were not significantly correlated with measured physical properties, the indications showed that the yield increased with decreased bulk density, increased air permeability and total porosity. DeBoodt, DeLeenheer and Kirkham (30) reported a curvilinear relationship of yield of mangolds to CMWD (change in mean weight diameter) of aggregates. Anderson and Kemper (4) reported highest yield when aggregate stability was 52.8 percent while low yield was found both in 32.3 percent and 73.2 percent aggregate stability. The yield determination was made on the dry weight of tops of potted corn plants grown for 8 weeks. Laws (66) found that the aggregation of medium and fine textured soils by addition of soluble silicates improved the yield of crops grown on these soils.

Synthetic soil aggregates provide a more suitable means of investigating the importance of soil structure to plant growth as these are capable of making profound changes in aggregation with only small direct effect on the microbiological population and nutrient status of soils. Experiments with soil aggregants have produced various results. Increases in yield sometimes have been large, as in the work of Aldefer (1) with lima beans, while decrease in yield was reported by Haise, Jensen and Alessi (46) with sugar beets. Experiments of Martin, et al. (71) on fine-textured soils with poor visual structure showed that soil aggregants produced various results.

According to Quastel's (102) review of experimental results, soil aggregants often caused an improvement in crops early in the season even though final yields were not increased. There is some indication that the importance of soil structure, as a limiting factor in plant growth, increases with density of plant population (48).

From the foregoing it is clear that the organic fraction of soils act both directly and indirectly in a variety of ways. Because the organic fraction affects plant growth in several different ways and because the relationship between the various effects is not fixed but variable, the significance of the soil organic fraction cannot be estimated from any single measurement.

B. Effect of organic matter on physical and chemical characteristics of soil

The role of organic matter in aggregation is well recognized. In order to understand the effect of organic matter on different characteristics of soil aggregates such as size, shape, strength, distribution, moisture retention, etc., it is necessary to consider the causes and mechanics of formation and destruction of aggregates.

A review on soil aggregate formation has been made by Russel (110), Stallings (117), and Martin (69). Studies on aggregate stability of soils from the western portions of the United States and Canada has been reviewed by Kemper and Koch

(60).

In the early work on aggregation, flocculation in dilute suspension was the basic concept of granulation and aggregate formation. In 1936, Bradfield (16) reported that granulation consists of flocculation plus the cementing or binding together of flocculated particles. Four main factors are thought to be responsible for the binding or cementing action; a) organic matter, b) microorganisms, c) soil colloids, and d) cations.

1. Factors involved in binding soil particles

a. Organic matter It is generally recognized that organic matter in some way has a favorable effect on the formation of aggregates in the soil. It also has been observed that the beneficial influence of organic matter is more or less directly proportional to the amount and character of organic matter applied to the soil (2,35,62,68,69,79,103, 127). This leads to the erroneous conclusion by some that the binding of soil particles into aggregates is due entirely to the physical effect of organic matter. In recent years, it has been noted that the application of large quantities of fresh or unleached organic matter in the form of barnyard manure, crop residues, mulches or other substances usually produced a rapid increase in the number of aggregates in soils immediately following application (119,127).

It has also been noted that the quality of organic matter involved, as well as the quantity is important (74). However, unless the initial application of organic matter was sufficiently large to produce a continuous supply of dissolved substances to the soil or was supplemented by additional applications at later dates, this initial increase in aggregate formation soon reached a climax. Subsequently, the number of aggregates in the soil underwent a steady decline. The change due to the addition of residues was related in some way to the biological activity in the soil (85). It was also concluded that the improved physical condition of the soil probably was due to the combined transitory and stable effects of the by-products of decomposition and to the large amount of cells and other materials synthesized by the microorganisms.

It was observed that organic materials which decomposed rapidly increased aggregation within a few days after they were incorporated with the soil, had their maximum effect in about 20 to 30 days and then gradually lost their effectiveness (117). The more rapid the rate of decomposition of the organic matter, the more rapid was the rate of aggregation (70).

Decomposing organic matter conferred a good structure on the soil and the more rapid the decomposition, the better was the structure (41). The explanation of this effect may be due to some substance which exists only temporarily in the soil and is formed as a by-product during decomposition.

A single application of organic matter when added to soils containing only a small amount of cementing materials necessary for the formation of stable aggregates, increased the number of large aggregates. On the other hand, the addition of organic matter to soils containing considerable quantities of either active inorganic or organic colloidal material did not change aggregation appreciably (24).

Bluegrass sod increased and maintained a higher percentage of aggregates of the larger sizes but was not as effective as mulch (2,47,126). The value of mulch in the formation of aggregates was out of proportion to the amount of organic matter added. Mulch and sod are more effective in aggregate formation in the top soil than in the subsoil or B-horizon. Mulch favored formation of large aggregates (118).

Sideri(113) concluded that the increase in aggregate formation was not due to the physical effects of organic matter but due to soluble substances including carbohydrates. The organic matter associated with the clay fraction and presumably adsorbed on the clay particle is the fraction most effective in aggregate stabilization.

Organic substances vary widely in their ability to granulate the soil and their effectiveness in this respect depends on the state of decomposition. For example, some organic constituents such as sugars do not stabilize soil granules directly (78). However, once transformed into microbial tissues and decomposition products, sugars become highly effective. Fungal filaments and certain decomposition products of bacteria, such as fats, waxes, lignins, oils, proteins and resins have a direct stabilizing effect (127).

Page (87) postulated that polar organic compounds may be thought of as playing two important roles in soil structure tending to stabilize naturally formed aggregates (1) weakening the otherwise strong cohesive bonds between clay particles thus permitting formation into aggregates instead of a solid mass and (2) linking clay particles together through mutual adsorption of such compounds by two or more clay particles.

b. Microorganisms Aggregating substances due to microorganisms may be of two groups, one consisting of the cells of microorganisms and their secretory products such as mucus, slime or gum produced during growth and the other consisting of materials such as polysaccharides synthesized by certain soil microorganisms.

The addition to the soil of rapidly decomposable substances, such as sucrose (76,90) and finely ground crimson clover (75,94) resulted in a large increase in the number of bacteria and a rapid increase in water stable aggregates. The more rapid the decomposition of cellulosic organic matter, the greater was the production of mucus, and hence the better was the resulting structure (41,51). The stability of aggregates varied with the mucus produced by the various organisms (89). The most viscous produced the most stable aggregates. It does not necessarily follow, however, that all viscous substances will improve soil structure.

Aggregation was greatly improved through the activity of certain fungi and bacteria (91). Increased structure stability resulting from biological activity is temporary, apparently remaining only as long as the stabilizing decomposition products exist. Soil organisms and their metabolic products were active in the formation and stabilization of soil structure (85) although they played a greater role in the stabilization than in formation (74). The temporary increase in aggregation frequently observed following incubation of soils with added organic material is related closely to microbial activity; the more favorable the incubation conditions are to microbiological decomposition of organic matter, the more rapid but more short lived are the ameleorative effects.

c. Soil colloids   Colloidal material has an increased cementation effect in aggregate formation. In soil, it exists in three forms--namely, as clay particles, irreversible or slowly reversible inorganic colloids like the oxides of iron and aluminum, and organic colloids. Baver (6) found that the smaller clay particles are usually more effective in the formation of aggregates than the larger ones and Boller and Stephenson (13) found that clay is more active in forming smaller aggregates than large ones.

In a number of nonlateritic soils the amounts of aggregation and their clay content were highly correlated when the organic matter content was low, and the amount of aggregation and the organic-carbon content were correlated where the clay content was low. However, there was little significant correlation in these soils between the amount of aggregation and one of these factors if the other was high. The effect of clay as a binding agent generally increased as the organic matter content of soil declined and decreased as the organic matter content increased (7). Clay and organic matter were about equally significant in aggregate formation.

A close relation between the free iron oxides and aggregation of southeastern soils was found by Lutz (67). Weldon and Hide (130) noted that stable aggregates were usually high in sesquioxides particularly in soils from sodium affected spots.

d. <u>Cations</u> Calcium is known to be a flocculating agent while sodium is a deflocculating agent. Massive application of sugar lime has increased aggregate stability of Belgian soils (30). Improvement of soil structure and yield as a result of added sugar lime (sugar refinery waste product, largely $CaCo_3$) under Belgium conditions is well documented (60). The deleterious effect on soil structure of replacing divalent with monovalent ions has been observed by many investigators (22,101). This effect is so well known as to provide the basis of most techniques for completely breaking soil aggregates into primary particles.

2. <u>Natural agencies involved in aggregate formation</u> Even though the nature of flocculation and cementing agents in soils is somewhat understood, there is no clear picture con-

cerning the processes of aggregate formation under natural conditions. The activity of root systems appear to be very important, acting to separate and compress small clumps of the soil, causing shrinkage and cracking due to dessication near the root, and making conditions favorable for activity of microorganisms at the surface of these units.

Periodic changes in moisture and temperature are considered to be processes responsible for aggregate formation. Alternate wetting and drying causes cracks or cleavage planes to develop due to differential swelling and shrinkage. Freezing causes localized pressure and makes the soil break up into rather small crumbs. Tiulin (124) considered that pressure and coagulation aid in aggregation. According to him, pressure produces more intimate contact between particles so that the cementing influences of water films are rendered more effective. Baver (7) has given a detailed review of literature concerning the role of the natural agencies in the process of aggregation.

Page (87) visualized the formation of aggregates in nature as follows:

> "Aggregates result primarily from the action of natural agencies by which parts of the soil are caused to clump together and separate from adjacent masses of soil. There are two kinds of processes involved (a) building up of aggregates from dispersed materials and (b) breaking down of large coherent masses into favorable sized aggregates. The second process is more important because most soils become more dense and compact with continuous farming, and the large masses are broken down through (a) the action of small animals like earthworms, (b) tillage practices, (c)

pressure at differential drying caused by freezing, (d) compression due to roots and (3) localized shrinkage caused by the removal of water by roots or evaporation."

Apart from these natural formations, as reported by Gish and Browning (43), a large number of factors influence size, distribution and stability of aggregates. Among these factors are methods of taking and handling samples, season of year, moisture content, past management practice and method of determining and expressing aggregation.

3. Structure of soil aggregates Soil aggregates may be thought of as a number of primary particles of sand, silt and clay connected in a special distribution in a state of equilibrium at a given temperature and moisture content. When aggregation occurs, the specific surface area and with it the total surface free energy of the solid particles within the soil diminishes. The reduction of surface energy considered as a driving force may be thought of as a mechanism for aggregation. As the surfaces of two solids approach one another, their fields of force begin to overlap, resulting in adhesion. Adhesion manifests itself by internal friction, seizure of two solids or aggregation of primary particles.

Russel (109) suggested a possible mechanism by which aggregates are bound together by clays. This theory was supported by experiments of Sideri (113) and Myers (84) from which they postulated that a direct binding occurred between clay particles of soil and certain polar organic compounds formed from soil organic matter.

Using electron microscopic techniques, Kroth and Page (63) suggested that polar organic compounds form physico chemical bonds with the surface active clays thereby forming aggregates which resist destruction on wetting. This general idea gained further support from the finding of Peterson (94) that montmorillonite was a more effective binding agent than kaolinite because of its greater surface and negative charge.

Recently, Emerson (36) reported a study on the structure of soil crumbs. According to his concept, the hypothesis of organic matter forming inter-crystalline complexes is untenable. From his previous work, he had concluded that clay crystals in soil crumbs formed by drying are oriented. Flakes of oriented calcium saturated clay do not disperse in distilled water unless mechanically disturbed. He defined a clay-domain as a group of clay crystals having suitable exchangeable cations which are oriented and sufficiently close together for the group to behave in water as a single unit. Emerson (36) thinks that the process of soil drying by roots may be enough to bring the clay aggregates together sufficiently close so as to form a domain. He hypothesized that organic matter and soil conditioners stabilize soil crumbs by increasing the strength of quartz-clay bond. The carboxylated polymers form bonds with quartz surfaces in addition to bonding clay crystals together. According to his model of a soil crumb, several clay domains are linked to each quartz particle.

The types of bonds could be (a) between quartz-organic matter-quartz, (b) between quartz-organic matter-domain, (c) between domain-organic matter-domain and (d) between domain-domain-edge faces. The limitations of the model proposed by Emerson (36) are that it applies only to soil crumbs in which the clay domains are free to take up their inter-crystalline water. Secondly, it does not apply to crumbs in which clay is purely kaolinite.

4. <u>Deterioration of soil structure</u> Cultivation of soil and various tillage processes lead to degradation of soil fertility and soil structure (7). Jenny (54) reported that 60 years of cultivation of the Putnam silt loam in Missouri had led to a 38 percent decrease in organic matter, a 33 percent decrease in available bases, and a corresponding decrease of aggregation. Baver (7) showed that the state and degree of aggregation of cultivated forest and prairie soils were much lower than that of soils from adjacent virgin areas. He summed up the effects as due to decreased organic matter production, increased organic matter decomposition, increased leaching, the impact of rain drops on exposed soil, and the mechanical manipulation of tillage implements.

The growing of crops affects the structure of the soil both directly and indirectly. The direct effects are protection afforded by the leaves and stems against the impact of raindrops which in turn retards deterioration of structure and the development of granulation and porosity through root activity which aids in regeneration of structure. The indirect effects are the changes in granulation caused by the organic matter produced by plant growth.

It is difficult to separate the direct and indirect influences of root activity on soil structure. It is difficult to distinguish between the aggregating effect of root pressure, binding qualities of root hairs, and moisture changes resulting from water usage.

Tillage operations may have varied effects upon soil structure depending upon nature of the implements and the moisture content at the time of manipulation. Any degradation of soil structure that results from tillage is not so much a question of unfavorable factors resulting from plowing as from the excessive manipulation of the soil after plowing (7).

Canopy of vegetation preserves the structure of the surface soil by preventing dispersion of soil by direct impact of raindrops although the exact extent of protection is not known. So also little is known concerning the effects of fertilizer on soil structure. Increased foliage and root production as a result of fertilizer applications has a great influence on the preservation and partial regeneration of structure (7).

Thus, in the simultaneous and complex process of formation and deterioration of soil structure, it may be said that little is understood of the different phases of aggregation.

While aggregates are being formed by the contribution of organic matter, microorganisms, cations, soil colloids, etc., the breakdown of aggregates are taking place due to cultivation, traffic, irrigation, weather and others under field conditions. The shape, size, configuration and stability of aggregates govern the porosity of the soil system and consequently the physical and chemical environment in which the plant roots grow. The relationships of air and water, essential for plant growth are dependent upon structure. Thus, in view of the key role played by structure in crop growth and soil management, there is an acute need for further investigation into this problem in order to understand the differences between the properties of different phases of aggregation dominated by the major influence of organic matter.

III. METHOD OF PROCEDURE

A. Plan of field experiment

The original objectives of the experiment were (1) to determine organic matter buildup or decline in the soil under continuous corn culture as influenced by application of different amounts and kinds of plant residues in the presence of ample supplies of nitrogen and (2) to determine the effect of the resulting differences in soil organic matter on soil physical characteristics. The treatment particulars are given in Table 1.

The residues calculated on the basis of 12 percent moisture are applied each fall and plowed under immediately. All residues except sawdust are run through a field chopper prior to application. The area is cropped to corn each year and prior to residue application all above ground portions of the corn are removed and the residues reapplied at the designated rate. The first residue application was made in the fall of 1953 and has been continued to the present time. At the time of residue application 20 pounds of nitrogen (N) per acre is applied for each ton of low nitrogen residue, i.e., all residues except alfalfa receive 20 pounds of nitrogen per acre per ton of residue in the fall at the time of residue application. In addition, the entire area receives 180 pounds of N per acre in the spring prior to corn planting. Ample amounts of P and K have been applied during the course of the experiment.

Table 1. Particulars of treatments

Tmt. No.	Symbol used[a]	Type of residue applied	Quantity of residue applied ton/acre	Quantity of N[b] applied lbs./acre	Time of application of residues	Remarks
1	F			180		Fallow plots
2	Ck			180		Corn grown
3	C_1	Cornstalks	1	180+20	Fall	in all other
4	C_2	Cornstalks	2	180+40	Fall	plots.
5	C_{2-2}	Cornstalks	2 + 2	180+40+40	2 tons in fall 2 tons in spring	
6	C_4	Cornstalks	4	180+80	Fall	
7	$\underline{C_8}$	Cornstalks	8/2	$180+\frac{160}{2}$	8 tons every second year fall	1953, 1955, 1957, 1959, 1961, 1963 and 1965
8	$\underline{C_{16}}$	Cornstalks	16/4	$180+\frac{320}{4}$	16 tons every 4th year fall	1953, 1957, 1961 and 1965
9	C_8	Cornstalks	8	180+160	Fall	

[a]The same symbol is used throughout for indicating the treatments.

[b]N applied in the form of ammonium nitrate.

Table 1 (Continued).

Tmt. No.	Symbol used	Type of residue applied	Quantity of residue applied ton/acre	Quantity of N applied lbs./acre	Time of application of residues	Remarks
10	A_1	Alfalfa hay	1	180	Fall	
11	A_2	Alfalfa hay	2	180	Fall	
12	A_4	Alfalfa hay	4	180	Fall	
13	A_8	Alfalfa hay	8	180	Fall	
14	S_4	Sawdust	4	180+80	Fall	
15	O_4	Oats straw	4	180+80	Fall	
16	G_4	Grass hay	4	180+80	Fall	
17	C_{16}	Cornstalks	16	180+320	Fall	One plot only

This experiment was started at the Soil Conservation Experimental Farm, Clarinda, Iowa, in the fall of 1953 by Dr. W. V. Bartholomew. Uniform plots of the size 20 x 40 feet were laid out in a field of 6 percent slope. The plots were subjected to slight erosion both by water and wind. The soil is of Marshall silty clay loam containing 36 percent clay, 56 percent silt and 8 percent sand.

B. Field measurements

1. Corn yields Corn yields have been recorded each year since the start of the experiment except in 1954 when drouth was extremely severe. Data on both the yield and population of corn per plot were collected. The yield was calculated on an acre basis and statistical analysis made by the procedure suggested by Snedecor (115). Yields of corn were recorded on 15.5 percent moisture basis.

2. Plant growth During the early years of the experiment no visual differences in corn growth was observed. However, during the past five years a peculiar chlorotic condition of plants was noticed during June of each year. The plants appeared yellow and stunted and were variable in growth. Certain plants were moderately yellow and stunted, whereas, plants in the same row a few feet distant might appear quite normal. The chlorotic condition found mostly in high residue plots, could not be identified with any particular nutrient element deficiency. In June 1964, 20 plants were selected at random

in each plot and height measurements made. Again in June 1965, plant height measurements were taken. In all years the chlorotic condition disappeared during mid-July, although growth differences remained.

3. Plant analysis It was suspected that the chlorotic conditions in 1964 resulted from sulphur deficiency. Hence, plants from Ck, A_8, and C_8 treatments were sampled, washed in distilled water, dried, ground and sent to the ARS Soil-Plant-Animal Nutrition Laboratory at Ithaca, New York, where sulphur determinations were made.

The chlorotic condition persisted in 1965 in spite of sulphur application, and thus deficiency of other nutrients was suspected. Twenty leaves in the middle two rows were collected at random and sent for spectographic analysis of elements to Ohio Agricultural Experimental Station during June 1965, when the plants were about 80 cm. in height. The analyses for NPK were made by the Soil Testing Laboratory at Iowa State University.

C. Collection of soil samples

Bulk samples from the surface 0 to 6 inches of all the 65 plots were collected from 4 locations randomly selected within the plot. Samples were taken after spring planting in May 1965, avoiding areas in the rows where cross travel of tractor wheels may have occurred. These samples were used for physical studies except for bulk density and aggregate size distribution.

Core samples 4 inches in diameter were taken from all plots from 0 to 3 inches and 3 to 6 inches in depth during the same time for studying aggregate size distribution and bulk density. Necessary care was taken in inserting and slicing off of the cores.

For chemical studies, the soil from each plot was sampled at the 0 to 6 and 6 to 12 inch depth by using a one-inch sampling tube. Samples were collected from 20 sites at random in each plot in the fall of 1964 before the application of residues.

During the course of physical analysis, it was felt that soil samples from the adjoining virgin meadow might be helpful for comparative purposes. Hence 4 sites were selected representing each replication along the borders of the experimental area and soil samples were taken during October 1965 in the same manner as for core samples described in paragraph 2.

Again to compare the characteristics of the soil of these plots with the soil of rotation experiments, core samples for 0 to 3 and 3 to 6 inches depth were collected from 3 replicated plots of the three rotations (continuous corn with 180-20+0 manurial treatment, continuous corn with 0+20+0 manurial treatment and corn-oats-meadow-meadow rotation) in the same farm during October 1965. The samples were collected in the same manner described in paragraph 2.

D. Preparation of soil samples

1. Physical studies The larger clods in the bulk sample of soil were broken by hand and the mass of soil was air dried and passed through a one-inch sieve. Repeated lots of about 500 g. samples of sieved soil were passed through the rotary sieve similar to the one developed by Chepil (26). Aggregates of the following size groups were obtained and stored in cartons: <0.5 mm., 0.5 to 1.0 mm., 1.0 to 2.0 mm., 2.0 to 3.0 mm., 3.0 to 5.0 mm., 5.0 to 9.0 mm., 9 mm. to 1 inch, and >1 inch.

2. Chemical studies The moist soil samples collected as indicated were spread in a cool room and allowed to dry slowly. When dried, the entire soil was ground finely and stored in air tight jars.

E. Determination of physical properties

1. Aggregate size distribution and bulk density The core samples of 0 to 3 inches and 3 to 6 inches depth collected for the above study were air dried and passed through the rotary sieve in the same manner as for the preparation of physical studies and each resulting fraction oven dried and their weight recorded. The different size distributions thus obtained fall under the following classes of <0.5 mm., 0.5 to 1 mm., 1.0 to 2.0 mm., 2.0 to 3.0 mm., 3.0 to 5.0 mm., 5.0 to 9.0 mm., 9.0 mm. to 1 inch, and >1 inch, and the data analyzed

for geometric mean diameter[1].

The bulk density of the soil samples were calculated by dividing the total oven dry weight of each sample by the total volume of cores used for the same. In both these cases studies were made on duplicated samples and their average reported.

2. Aggregate strength   Rupture stress and rupture strain of individual aggregates of the 3 to 5 mm. size groups were made by the method outlined by Rogowski (106). Measurements were made on forty aggregates each from F, Ck, C_4, A_4, S_4, O_4, G_4, C_8 and C_{16} treatments using the apparatus developed by Rogowski (106).

The values of initial diameter of aggregates and the resulting change in diameter due to loading were read from dial indicators. The load at rupture was computed from the deflection of ring dial. The energy of rupture was computed from the equation suggested[2] by Rogowski et al. (108) for each aggregate and the average of forty aggregates was taken to give energy of rupture of each treatment. Computations and statis-

---

[1]The geometric mean diameter computations were made by Dr. R. R. Allmaras, Morris, Minnesota, using the methods outlined by Allmaras et al. (3).

[2]The equation is as follows:

$$\text{Tr (ergs./cm.}^2) = \frac{1.80\ P\Delta d}{(\pi d)^2} \cdot \frac{\text{dyne cm.}}{\text{cm}^2} \text{ where}$$

Tr = Energy of rupture
P = Load in dynes (computed from deflection of dial ring and the manufacturer's graph)
Δd = Change in aggregate polar diameter in cm.
d = Aggregate polar diameter in cm.

tical analyses were performed by a computer.

3. <u>Aggregate strength under different pressures</u> To study the effect of different pressures on different sizes of aggregates for their withstanding capacity, size groups of 5.0 to 10.0, 3.0 to 5.0, 2.0 to 3.0, 1.0 to 2.0, 0.5 to 1.0 mm. were subjected to different pressures of 100, 250, 500 and 1,000 pounds per square inch. In carrying out the above work, the following procedure was followed:

a. Pass the different size groups of aggregates obtained by rotary sieve through the different sieves used for wet sieving and select a representative sample of 10 g. each.

b. Spread the aggregates over a 4 x 6 inch size brown paper, placed on a thick aluminum sheet of the same size. The aggregates should be packed as closely as possible in a single layer.

c. Place the sheet on the platform of a hydraulic press fitted with a gauge to measure up to a pressure of 2,000 pounds per square inch.

d. Cover the upper side of the aggregate with a brown paper of the same size of the aluminum sheet and apply the required pressure.

e. Place the treated aggregates on a nest of sieves of different sizes used for wet sieving and sieve them subject to uniform force and time.

f. Weigh each component left in the sieve and calculate the percentage of each size group obtained.

Aggregates from F, Ck, A_4 and A_8 were used, quadruplicate samples analyzed and the average taken.

4. Aggregate stability The water-stable aggregates were determined by the wet-sieving procedure outlined by Kemper and Chepil (59) except that only 10 g. of each sample were used and no correction was made for the sand content. The determinations were made in quadruplicate and their average taken.

5. Compressed aggregates and their stability In order to study the effect of pressure and incubation on the stability of the natural aggregates and their ground material, the following four types of compressed aggregates were prepared.

i) Aggregates moistened, pressed, broken and air dried

ii) Aggregates moistened, pressed, broken, incubated and air dried

iii) Aggregates ground in a grinding machine, moistened, pressed, broken and air dried

iv) Aggregates ground in a grinding machine, moistened, pressed, broken, incubated and air dried

In the preparation of compressed aggregates, the following procedure was adapted:

a. Bring aggregates approximately to field capacity (33 percent moisture by weight) by spraying the aggregates with a fine spray and a measured amount of water. Let the moisture content equilibrate overnight in a humidity chamber.

b. Compress the wetted samples in a hydraulic press to 1,000 pounds per square inch.

c. Break out aggregates separating the pressed soil at the edges of the pressed cake by means of a sharp knife and discarding.

d. Place a portion of the pressed aggregates in an incubation bottle, tie with polyethylene sheet over the mouth to permit air but to prevent escape of moisture and incubate at 30° C. for 30 days.

e. Spread the other portion of aggregates in a cool dry place for air drying and then determine water stability.

The aggregate stability of the compressed aggregates was determined in the same way as the natural aggregates. The ground soil material was treated in the same way as the compressed aggregates of the type (iii) and iv). In the preparation of compressed aggregates only the following 9 treatments, namely, F, Ck, C_4, C_8, C_{16}, A_2, A_8, G_4 and Meadow were selected and the average of duplicate samples reported.

6. Moisture retention The pressure plate apparatus described by Richards (104) was used for determining the moisture retention at suction levels of 0.10, 0.33, 1.0, 3.0, 5.0 and 15.0 bar. Whole soil samples of 0 to 6 inch depth prepared

for chemical analysis of the treatments F, Ck, C_4, C_8, C_{16}, A_4, S_4, O_4 and G_4 were used for these determinations and the average of duplicate samples reported.

F. Determination of chemical properties

1. Undecomposed organic residues[1] The quantity of undecomposed organic residues was determined as follows:

a. Take 100 g. of ground soil material prepared for chemical analysis in an incubation bottle. This soil material was not subjected to sieving in its preparation. Add 500 ml. distilled water and shake until the soil is dispersed.

b. Add 10 ml. calgon (50 g. dissolved and diluted to 1 liter of water), shake thoroughly and keep it dispersed for 24 hours.

c. Pour the entire material in a 1,000-ml. beaker. The undecomposed material will float to the top.

d. Collect the floating material by careful decantation into a 0.25 mm. sieve. Repeat the same 5 to 6 times until all the floating material is collected in the sieve. This material is essentially free of soil particles.

e. Transfer the collected material to a 100-ml. beaker and dry it in an oven at 70° C. for 24 hours and the

[1]The material that can be seen by the naked eye and that can be separated by water. This method may not separate all of the undecomposed residues from the soil. Rather it probably gives an arbitrary method for comparing the treatments.

oven-dried material is weighed as undecomposed organic residue.

The determinations were made on duplicated samples and their average taken.

2. Organic carbon content   The organic carbon content of all the different plots of 0 to 6 and 6 to 12 inch depths was determined by the wet combustion method of Mebius (80). Representative sample out of the soil prepared for chemical analysis was again ground by mortar and pestle and the determinations made. In the case of the 0 to 6 inch soil, selected duplicates were compared. For 6 to 12 inch soil, the four replicates were mixed in equal quantity and analysis made.

3. Soil pH   Soil pH of all the soil samples of 0 to 6 and 6 to 12 inches were determined by the glass electrode pH meter as described by Frederick and Murphy (39). The soil-water ratio used was 1:2.5. All determinations were made in duplicate and their average taken.

G. Statistical analysis

Because the corn populations in the field were somewhat variable, the covariance analysis suggested by Snedecor (115) was used to compute the corn grain yield for each treatment based on a uniform plant population. The significance of the adjusted differences was tested. In testing the yield decline for the different rates of residue application for the years 1963 to 1965, the regression coefficient was calculated along with the regression equation and their significance tested.

In the aggregate strength studies, the mean rupture strength ± standard error of the mean was calculated.

The data on organic carbon and soil pH were analyzed by the procedure suggested for a randomized complete block design and their significance tested. For comparing the individual treatment means, least significant difference was used.

H. Figures and graphs

In drafting the figures and graphs, the average of all the four replications were taken except for C_{16} where only one plot was available.

IV. RESULTS AND DISCUSSION

A. Undecomposed organic residues

The quantity of undecomposed organic residues from the different treatments are shown in Figure 2. The detailed data is given in Table 2 and the statistical analysis in Table 21 in the Appendix. The curve indicates that at higher levels of cornstalk application, the quantity of undecomposed material increased considerably. In comparing the effects of cornstalks with alfalfa hay, no difference is seen at the 1 and 2 ton level of application. However, at the higher levels of application, the undecomposed residues from cornstalks is greater. For example, the quantity of undecomposed material is 0.112 g. for A_8, and is 0.226 g. per 100 g. of soils in C_8 (Table 2). In case of equal quantities of different kinds of residues, there is a larger quantity of undecomposed material in S_4.

Russel (109) enumerated the following conditions for rapid decomposition of plant products.

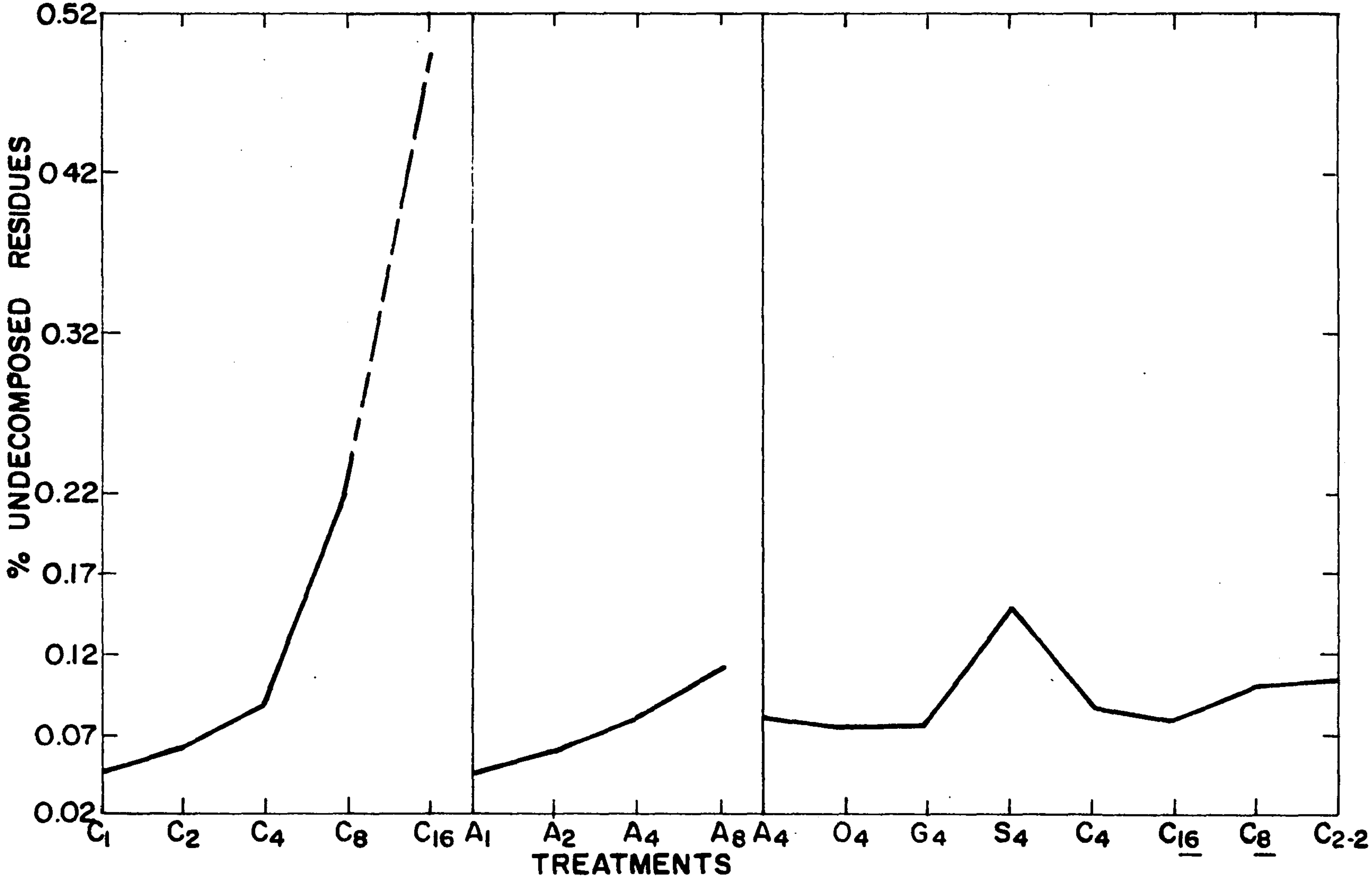
1. The material should have a low lignin and probably also a low wax content.

2. The material should be in as fine a state of comminution as possible.

3. There should be an adequate supply of available nitrogen.

4. The pH should not be allowed to fall too low, otherwise the microbial population becomes unduly restricted.

Figure 2. Percentage undecomposed organic residues per 100 g. soil in 0 to 6 inches soil depth as influenced by the type, amount and time of application during the years 1953 to 1963, inclusive. (The treatment symbols are indicated in Table 1.)



% UNDECOMPOSED RESIDUES
0.52
0.42
0.32
0.22
0.17
0.12
0.07
0.02
C1
C2
C4
C8
C16
A1
A2
A4
A8
A4
O4
G4
S4
C4
C16
C8
C2-2
TREATMENTS

Table 2. Amount of organic residues applied in 0 to 6 inches depth and their percentage decomposition (in 100 g. soil)

Tmt. No.	Name of tmt.	Amount of residue at a time in g.	Total residue up to 1964 in g.	Amount undecomposed	% Decomposed	% Undecomposed
1	F	-	-	-	-	-
2	Ck	-	-	-	-	-
3	C_1	0.088	0.968	0.047	95.1	4.9
4	C_2	0.176	1.936	0.066	96.6	3.4
5	C_{2-2}	0.176	3.872	0.101	97.4	2.6
6	C_4	0.352	3.872	0.089	97.7	2.3
7	$C_{\underline{8}}$	0.704	4.224	0.101	97.6	2.4
8	$C_{\underline{16}}$	1.408	4.224	0.081	98.1	1.9
9	C_8	0.704	7.744	0.226	97.1	2.9
10	A_1	0.088	0.968	0.049	94.9	5.1
11	A_2	0.176	1.936	0.062	96.8	3.2
12	A_4	0.352	3.872	0.082	97.9	2.1
13	A_8	0.352	7.744	0.112	98.5	1.5

Table 2 (Continued).

Tmt. No.	Name of tmt.	Amount of residue at a time in g.	Total residue up to 1964 in g.	Amount undecomposed	% Decomposed	% Undecomposed
14	S_4	0.352	3.872	0.152	96.0	4.0
15	O_4	0.352	3.872	0.075	98.1	1.9
16	G_4	0.352	3.872	0.078	98.0	2.0
17	C_{16}	1.408	15.488	0.505	96.7	3.3

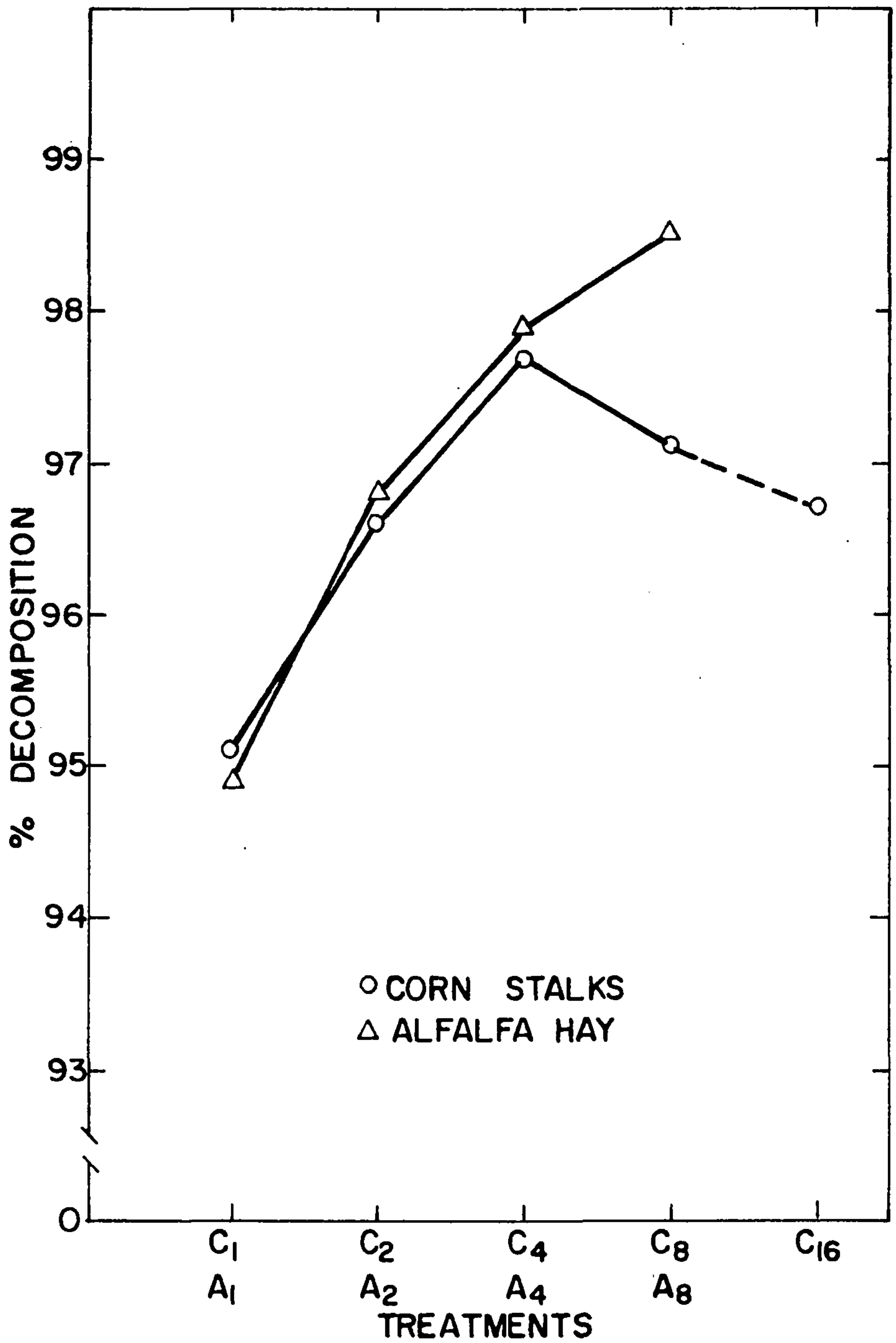
5. The aeration should remain good and the moisture supply adequate.

6. The temperature should be fairly high, the maximum rate of decomposition being between 30° C. to 45° C.

The percentage decomposition of cornstalks and alfalfa hay is shown in Figure 3. The calculations are based upon the total quantity of residue applied for the 11 years (1953 to 1963). The figure clearly indicates that in the case of alfalfa hay, the percentage decomposition increased with the rate of application over the entire range. But in the case of cornstalks, the percentage of decomposition increased only up to the 4 ton level and decreased sharply at the 8 and 16 ton level. This reflects the increased quantity of undecomposed material referred to in the previous page.

Peevy and Norman (93) have indicated that the composition of plant material influences the quantities and properties of decomposed material and they concluded that the higher the lignin content, the lower the rate of decomposition. Broadbent (19) reported that the relative rates of decomposition of plant materials in soils were found to be inversely related to the quantity added. Hutchinson and Richards (52) reported that for every 1,000 pounds of dry straw containing 0.5 percent nitrogen between 7 and 7.5 pounds of nitrogen are required to decompose it. Waksman (128) concluded that on theoretical grounds, the nitrogen content of organic materials must be 2 to 2.5 percent (C:N ratio 21 to 17) in order for a ready

Figure 3. Percentage residue decomposition of cornstalks and alfalfa hay in 0 to 6 inch soil depth as influenced by their rate of application during the years 1953 to 1963, inclusive.



99
98
97
96
95
94
93
0
% DECOMPOSITION
○ CORN STALKS
△ ALFALFA HAY
C_1
A_1
C_2
A_2
C_4
A_4
C_8
A_8
C_{16}
TREATMENTS

release of ammonia to occur, especially if fungi predominates. Jensen (56) observed that the critical C:N ratio of fresh plant material decomposing in an alkaline soil was 20 to 25 but in an acid soil was 13 to 18. He attributed this difference to the higher nitrogen requirement of fungi which predominates in acid soil.

In this experiment, the nitrogen applied for residue decomposition was 20 pounds per ton. Assuming cornstalks containing 39.9 percent carbon and 0.59 percent nitrogen as reported by Flaig (38) the C:N ratio is 1:23 after adding the applied nitrogen for decomposition and calculating on oven dry basis for the residue applied. On the other hand for alfalfa hay the C:N ratio is 1:14.5 on the basis of 41.8 percent carbon and 2.88 percent nitrogen. Preliminary analysis made on the different forms of nitrogen (Table 3) do not indicate any deficiency of nitrate nitrogen for decomposition in the C_8 treatment. Visual inspection showed that the alfalfa residues were chopped much finer than the cornstalks. In addition, it is likely, in view of differences on plant maturity and in the plants themselves that the cornstalks had a higher lignin and less readily decomposed organic content. All these factors probably contributed to the high percentage of undecomposed material found in the C_8 treatments.

Table 3. Different forms of soil nitrogen obtained from the three treatments analyzed on 6-17-65

Treatments	Nitrogen in ppm.			
	NH_4	NO_3	NO_2	Total
Check	26	82	2	110
A_8	25	157	3	185
C_8	35	118	1	154

B. Organic carbon[1]

1. Build up of organic matter The relationship of organic carbon content to the different treatments is shown in Figure 4. The detailed data is given in Table 4 and the statistical analysis in Table 22 in the Appendix. The percent organic carbon for the different rates of residue application of cornstalks and alfalfa hay and for the different kinds of residue of equal quantity are given separately for the two soil depths studied. The organic carbon includes the undecomposed residues. In 0 to 6 inches soil, the undecomposed residues indicated earlier were subtracted from the organic carbon content on the basis of 40 percent carbon for the residues. The resulting curve is shown in the graph. Except in

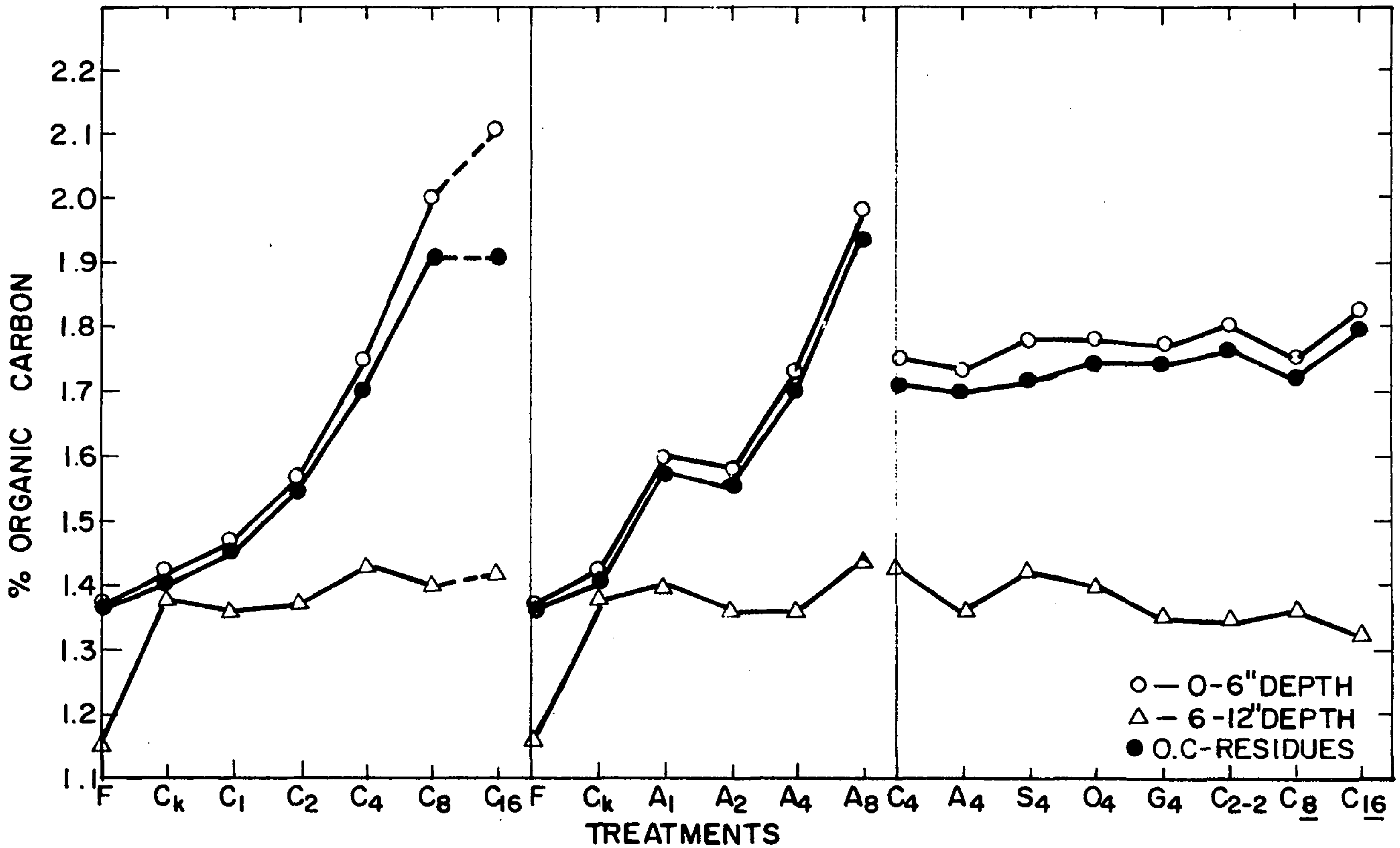
[1]The term organic carbon has been used here for better representation in view of the controversy over the conversion factor for organic matter. Wherever the term organic matter is used, it is assumed to contain 1.724 times of organic carbon.

Figure 4. Organic carbon content in 0 to 6 and 6 to 12 inches soil depth and content of decomposed residues as influenced by the type, amount and time of application of organic residues during the years 1953 to 1963, inclusive. (The treatment symbols are indicated in Table 1.)

Curve 1--Organic carbon including undecomposed residues in 0 to 6 inch soil depth.

Curve 2--Organic carbon including undecomposed residues in 6 to 12 inch soil depth.

Curve 3--Organic carbon by substracting the carbon content of undecomposed residues.



% ORGANIC CARBON
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
F
Ck
C1
C2
C4
C8
C16
F
Ck
A1
A2
A4
A8
C4
A4
S4
O4
G4
C2-2
C8
C16
TREATMENTS
○ — 0-6" DEPTH
△ — 6-12" DEPTH
● O.C-RESIDUES

Table 4. Percentage organic carbon for two soil depths of 0 to 6 and 6 to 12 inches as influenced by the cumulative effects of different organic residues applied at different rate and time over a period of 11 years

Tmt. No.	Treatment	Av. organic carbon		Increase over F	
		0 to 6"	6 to 12"	0 to 6"	6 to 12"
1	F	1.37	1.15	-	-
2	Ck	1.42	1.38	0.05	0.23
3	C_1	1.47	1.36	0.10	0.21
4	C_2	1.57	1.37	0.20	0.22
5	C_{2-2}	1.81	1.34	0.44	0.19
6	C_4	1.75	1.43	0.38	0.28
7	$C_{\underline{8}}$	1.67	1.36	0.30	0.21
8	$C_{\underline{16}}$	1.83	1.32	0.46	0.17
9	C_8	2.00	1.40	0.63	0.25
10	A_1	1.60	1.40	0.23	0.25
11	A_2	1.58	1.36	0.21	0.21
12	A_4	1.73	1.36	0.36	0.21
13	A_8	1.98	1.44	0.61	0.29
14	S_4	1.78	1.42	0.41	0.27
15	O_4	1.78	1.40	0.41	0.25
16	G_4	1.78	1.35	0.41	0.20
17	C_{16}	2.11	1.42	0.74	0.27

the case of C_{16} and to a certain extent in S_4, the curve runs parallel to the original. The difference in C_{16} and S_4 may be due to the high amount of undecomposed residues explained earlier.

In the 0 to 6 inch soil depth, the result clearly shows an increase in organic carbon with increasing amounts of application of residues. Equal applications of 4 tons per acre of different kinds of residues produced equal increases in organic carbon content in the 0 to 6 inch soil. Although there are differences in the chemical composition of the different types of residues, their ultimate ability in increasing organic carbon content in the soil over a period of years seem to be the same. This is also borne out by the fact that treatments A_8 and C_8 contain similar amounts of organic carbon.

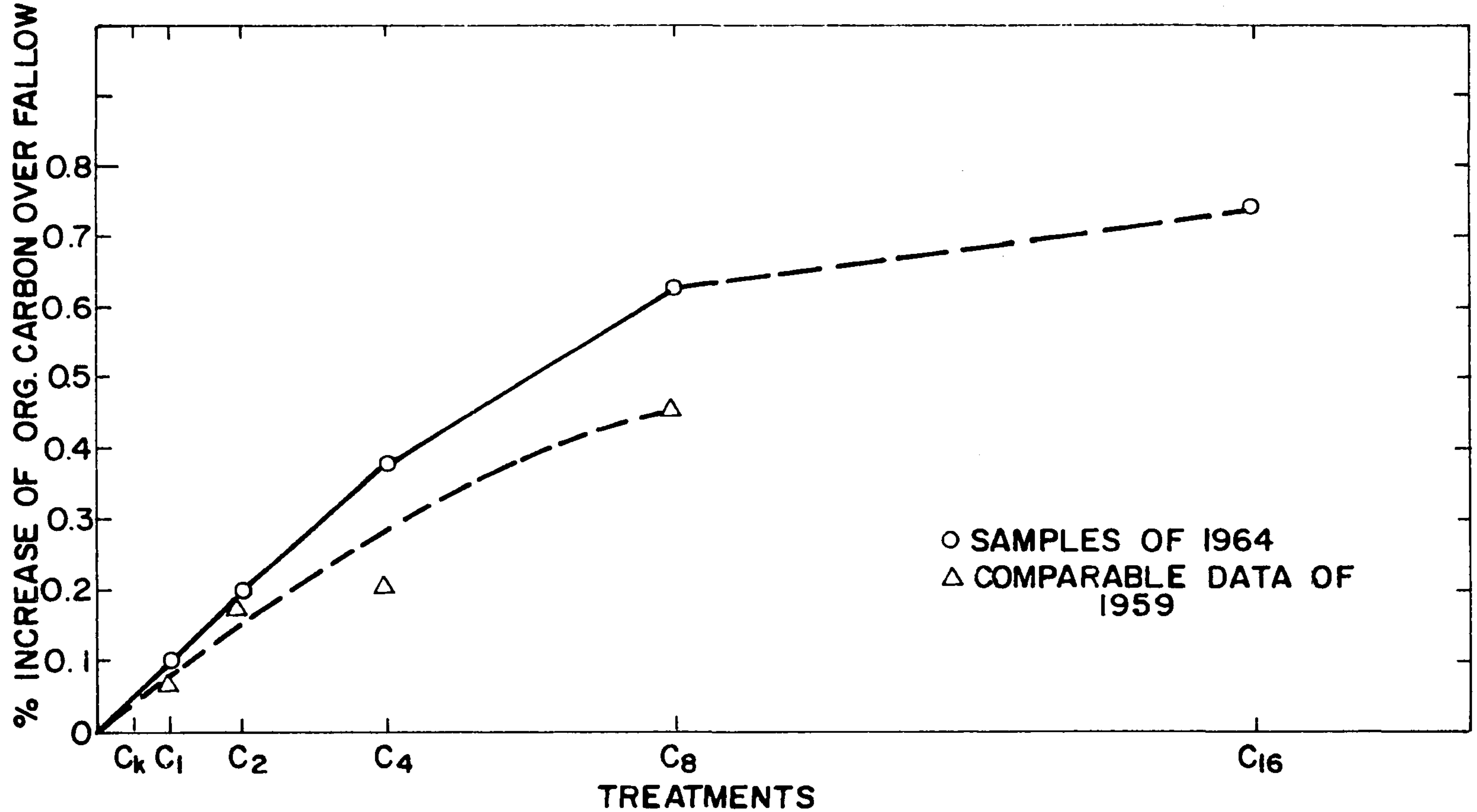
In the subsurface soil (6 to 12 inches) the amount of organic carbon is nearly constant regardless of treatment except that the fallow plot is much lower than the others. The sharp increase in organic carbon in the 6 to 12 inches in Ck over F denotes the effect of root residues influencing the organic carbon content in the above depth.

Russel (109) postulated that organic matter content of soil increases with the rate at which plant remains are added to soil, though it also depends on the way they were incorporated with it. Holtz and Vandecaveye (49) reported that annual application of organic residues were effective in increasing humus content of soil and that the gain in humus is proportional to the amount of nitrogen supplied by means of organic residues. Pinck _et_ _al_. (98) reported marked increase in soil carbon following addition of green manure crops and also when nitrogen only were added. The increase in nitrogen alone due to root residues amounted to as much as 30 percent. Broadbent and Bartholomew (21) reported that highly available energy material like sucrose may bring about a net decrease in soil organic matter when applied to soil containing active inorganic or organic colloidal material.

The organic matter buildup in this experiment is in general agreement with the findings cited above. It also indicates, that the different residues though different in original composition tend to produce soil organic matter with the same total carbon content. The sharp increase of organic carbon in the 0 to 6 inch soil as compared to 6 to 12 inch soil clearly indicates that large amounts of residues applied over a period of years has little influence in organic matter buildup in the subsurface soil under continuous corn culture. This emphasizes the need to protect the surface soil from erosion if organic matter is to be maintained at highest possible level under normal residue management practices.

2. _Effect of root residues_ The increase of organic carbon over fallow with different rates of cornstalks application is shown in Figure 5 and Table 4. The result indicates that up to a quantity of 4 tons of residue application, the

Figure 5. Increase of organic carbon content over fallow treatment in 0 to 6 inches soil depth as influenced by the different rate of cornstalk application during the years 1953 to 1963, inclusive, along with comparable data of 1959.


% INCREASE OF ORG. CARBON OVER FALLOW
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Ck
C1
C2
C4
C8
C16
TREATMENTS
○ SAMPLES OF 1964
△ COMPARABLE DATA OF 1959

increase in organic carbon is almost in direct proportion of the quantity of residues applied. While there is an increase of 0.1 percent for C_1, the increase is 0.2 percent for C_2 and 0.38 percent for C_4 treatments. The increase in the case of the check treatment accounts for 0.05 percent indicating that the buildup would have been resulted from corn roots equivalent to 0.5 ton of residue application per acre per year.

Russel (109) quoting Pavlychenko's results in the central prairie states of the United States of America and Canada reported 11.1 hundred weights (1,352 pounds) per acre of roots for wheat crop near harvest, and considerably more roots under prairie grasses in the surface depth of 10 cm. soil. Similar quantities of grass roots have been reported by Prince et al. (99) and Weaver (129). Thus, the equivalent of 0.5 ton (1,000 pounds) of root residues from check plots calculated from the rate of increase of organic carbon over fallow plot seems to be possible and reasonable.

3. Maximum level of organic matter   The curve in Figure 5 also indicates that after a particular level of residue application, the curve levels off indicating very slow increase in organic carbon content irrespective of the quantity of residue added. As seen from Table 4, while the increase of organic carbon is 0.38 percent between F and C_4 treatments for an application of 4 tons of cornstalks, the increase is 0.25 percent between C_4 and C_8 treatments for the next addition of 4 tons, and only 0.11 percent for the

subsequent addition of 8 tons between C_8 and C_{16} treatments. Thus, the figure and table clearly shows that above a particular level of organic carbon content, further increase is very slow in spite of added residue application. This is also demonstrated by the curve No. 3 between the treatments C_8 and C_{16} in Figure 4.

Russel (109) concluded that the organic matter content of an arable soil tends to an equilibrium value depending on the crop rotation practiced. Jenny (55) emphasized the tendency of soils to come to equilibrium in their nitrogen content as a result of counterbalancing the losses and gains. Prince, et al. (100) reported that while manured plots were capable of maintaining 87 percent of original soil nitrogen, the non-manured plots maintained 65 percent after a 40-year study of nitrogen fertilizers, thus, indicating the maximum and minimum level in which nitrogen is maintained. Bear and Prince (10) reporting on the organic matter content of New Jersey soils stated that by good management, the organic matter of a soil that has a normal value of 2 percent may be raised rapidly to 2.5 percent but any further rise will be difficult to effect. Under poor management, it may fall as low as 1.5 percent but further loss will be very slow. In good management they include crop rotation with a leguminous crop, addition of normal crop residues, erosion control and maintainance of of yield level of crops grown. Similar reports have been made by Dodge and Jones (33), Giddens et al. (42) and Morachan (83).

The curve shown in Figure 5 indicates that after attaining a level of about 2 percent organic carbon (equivalent to about 3.4 percent organic matter) further increase is very slow. The data reported by Slater and Carleton (114) and Johnston _et al_. (57) indicate no increase in the organic matter content of 3.4 percent in continuous meadow from 1931 to 1942 for the same soil type on the same farm as the experiment reported herein. Thus, the above data indicates the possible maximum level of organic matter of soil found in the experimental farm.

4. _Increase over time_ The percentage increase of carbon over time from 1959 to 1964 is shown in Figure 6. As the soil samples in 1953 were lost, due to a fire, the organic carbon content was assumed to be 1.2 percent at the beginning of the experiment. The above assumption was arrived at by taking into consideration the carbon content of fallow plot in 1959 reported by Larson (64) as 1.22 percent and considering the lowest carbon content of fallow plot in the surface and subsurface soil analyzed by me at 1.14 percent and 1.15 percent as shown in Table 4. The assumption is made for demonstrative purpose only.

The results indicate the similarity in the pattern of increase of organic carbon from increasing applications of cornstalks and alfalfa hay. When residues of equal quantity were applied, the differences in organic carbon content of the soil between treatments tend to decrease from 1959 to 1964.

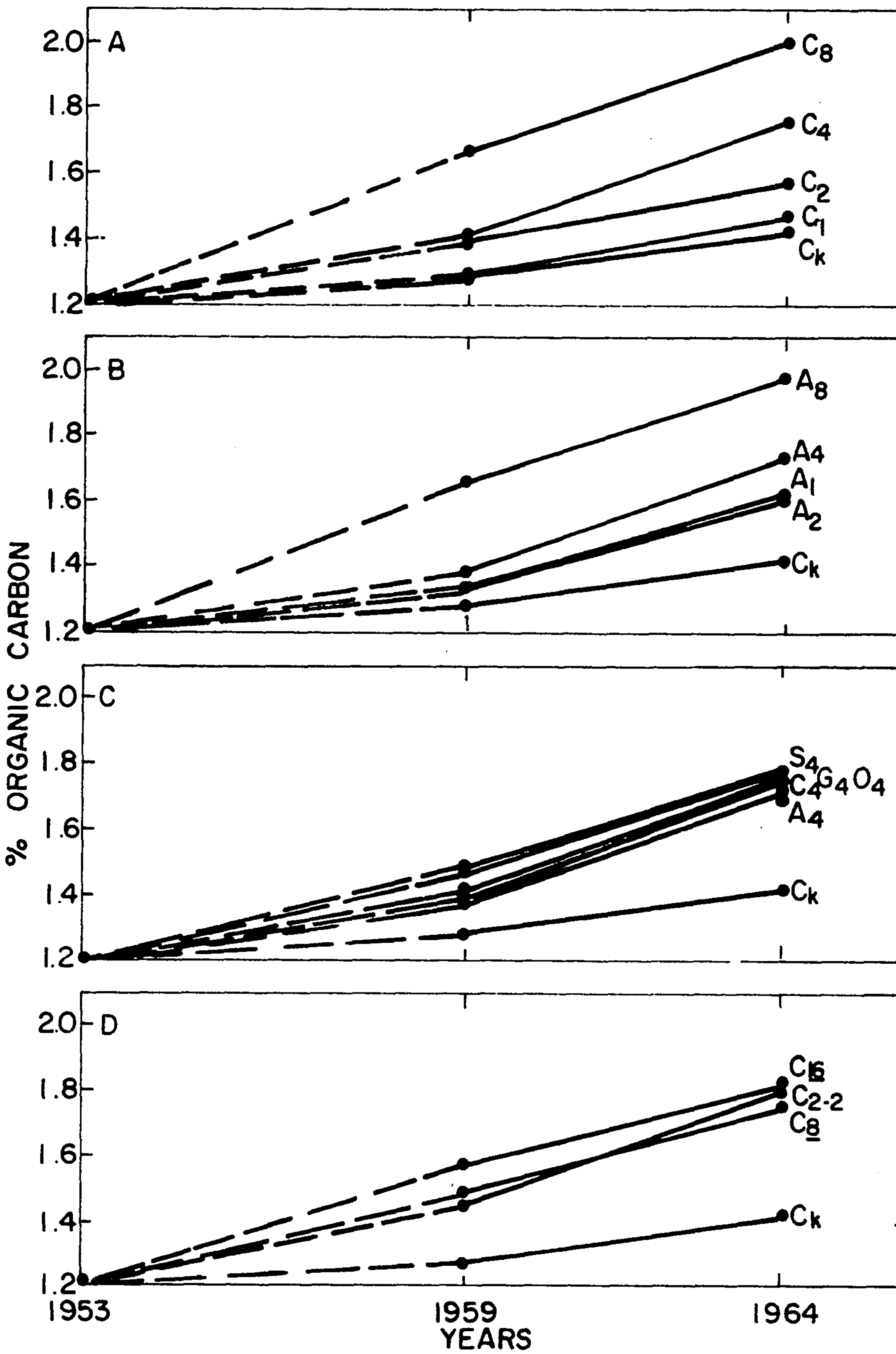
Figure 6. Organic carbon content for the years 1953, 1959 and 1964 in 0 to 6 inches soil depth as influenced by the type, amount and time of application of organic residues during the years 1953 to 1963, inclusive.

A--Different rates of cornstalk and check.

B--Different rates of alfalfa hay and check.

C--Equal amount of different kinds of residues and check.

D--Cornstalks of different amounts applied at different times and check.



2.0
1.8
1.6
1.4
1.2
A
C8
C4
C2
C1
Ck
B
A8
A4
A1
A2
Ck
C
S4
G4
O4
C4
A4
Ck
D
C16
C2-2
C8
Ck
% ORGANIC CARBON
1953
1959
1964
YEARS

A similar trend is seen when comparing treatments having applications of equal quantity of residues, but applied at different times. The differences may be due to the time required for decomposition of the residues.

Thus, it can be concluded from the above results that irrespective of type of residue and time of application, equal quantities of residue application tend to produce a similar increase of organic carbon over a period of years.

C. Soil pH

The effect of various treatments on soil pH for the two depths 0 to 6 and 6 to 12 inches are shown in Figure 7 and Table 5. The statistical analyses are given in Table 23 (Appendix). The graphs indicate highest pH in the check plot in the surface soil and reduction in all other plots depending on their treatments. In the cornstalk residue treatment, the annual application of N varied from 200 pounds per acre for C_1 to 340 pounds per acre for C_8 and 500 for C_{16}. All alfalfa residue treatments received an annual application of 180 pounds N per acre. The decline in soil pH reflects differences in nitrogen application both from the fertilizer and the residue treatments. However, the nitrogen from the fertilizer was no doubt dominant in decreasing the soil pH. The figure also indicates sharp decline of pH in the fallow plot as compared to check plot, both of which receives the same amount of nitrogen fertilizers indicating the crop effect in slowing the

Figure 7. Soil pH in 0 to 6 and 6 to 12 inches soil depth as influenced by the type, amount and time of application of organic residues and associated N treatments during the years 1953 to 1963, inclusive. (The treatment symbols are indicated in Table 1.)

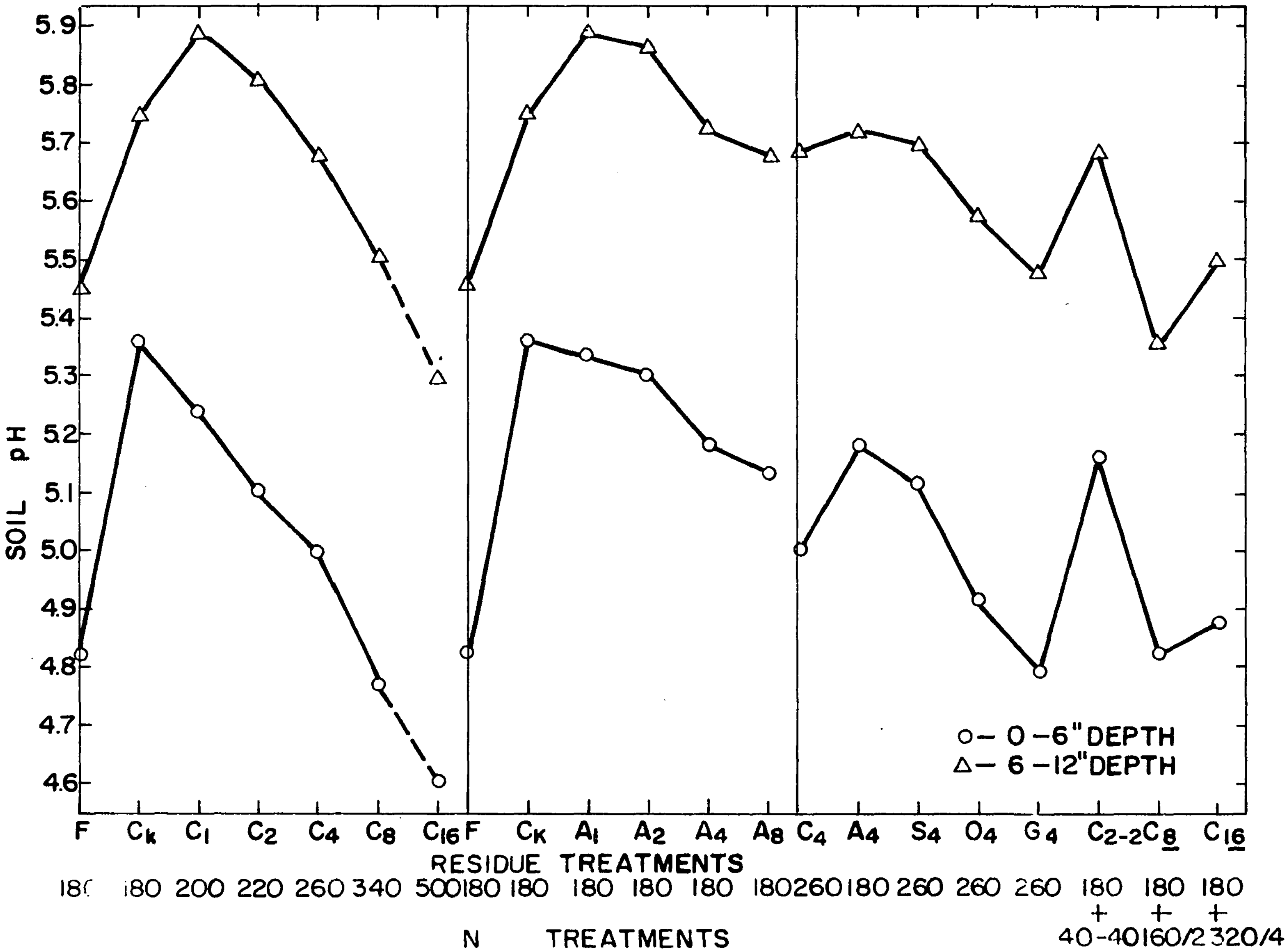

SOIL pH
5.9
5.8
5.7
5.6
5.5
5.4
5.3
5.2
5.1
5.0
4.9
4.8
4.7
4.6
○ – 0 – 6" DEPTH
△ – 6 – 12" DEPTH
F Ck C1 C2 C4 C8 C16 F CK A1 A2 A4 A8 C4 A4 S4 O4 G4 C2-2 C8 C16
RESIDUE TREATMENTS
180 180 200 220 260 340 500 180 180 180 180 180 180 260 180 260 260 260 180 + 40-40 180 + 160/2 180 + 320/4
N TREATMENTS

Table 5. Soil pH for the two soil depths of 0 to 6 and 6 to 12 inches as influenced by organic residues and N application over a period of 11 years

Tmt. No.	Tmt.	Av. rate of N applied per acre in pounds	Soil pH	
			0 to 6"	6 to 12"
1	F	180	4.87	5.45
2	C_k	180	5.26	5.75
3	C_1	200	5.23	5.89
4	C_2	220	5.12	5.81
5	C_{2-2}	260	5.15	5.69
6	C_4	260	4.99	5.68
7	$C_{\underline{8}}$	260	4.81	5.35
8	$C_{\underline{16}}$	260	4.92	5.50
9	C_8	340	4.76	5.51
10	A_1	180	5.33	5.89
11	A_2	180	5.28	5.86
12	A_4	180	5.18	5.72
13	A_8	180	5.12	5.68
14	S_4	260	5.12	5.70
15	O_4	260	4.92	5.57
16	G_4	260	4.81	5.47
17	C_{16}	500	4.60	5.30

decline of soil pH.

Equal quantities of different types of residue produced dissimilar pH. A_4 has the highest pH followed by S_4. Among the different treatments having equal residue application, A_4 alone did not receive any additional N for the purpose of decomposition. Hence the highest pH in A_4 may be attributed to the lesser quantity of nitrogenous fertilizer application. In comparing the C:N ratio for different organic residues, Millar *et al*. (81) reported a ratio of 400 for sawdust and 60 for cornstalks. Hence the higher pH in sawdust may be due to the very low N content in the residues. Among the treatments of time of application, C_{2-2} has a higher pH as compared to $C_{\underline{8}}$ and $C_{\underline{16}}$. This difference is unexplainable and needs further investigation.

The similarity of curves at both depths, 0 to 6 and 6 to 12 inches, indicates that the acidity has permeated to the lower depths also in the same proportion due to leaching effect. This may also be partly due to the physical mixing by plowing at greater depths than 6 inches. It is of interest to note that the carbon content among treatments is nearly the same in the 6 to 12 inch depths inspite of large variations in the 0 to 6 inch depth. In contrast, the pH among treatments in the 6 to 12 inches varies almost in the same manner as at the 0 to 6 inch depth.

The leaching action of water percolating through the soil is the most important single factor in removing bases to produce an acid soil (12). Although large quantities of carbonic acid are produced in soils by microorganisms and higher plants, the effect is relatively small, since most of the carbonic acid decomposes and is lost to the atmosphere as carbon dioxide.

Another important source of soil acidity is from acid-forming fertilizers. Pierre (96,97) working on different types of fertilizers reported that all fertilizers containing ammoniacal nitrogen caused increases in soil acidity. He also reported that soil type has insignificant effects on the total amount of acids formed by acid-forming fertilizers. He worked out a theory to account for the effect of different fertilizers on soil acidity and proposed a method to estimate the acid-forming tendency of fertilizers (95).

From the foregoing, it is clear that the high level application of nitrogeneous fertilizers in the residue treatments is the major contributory factor to the decrease in the soil pH. The decrease in pH is closely related to the increase in N application used for the decomposition of residues. The differences in pH between F and Ck treatments receiving the same amount of fertilizers can be attributed to the higher salt content in the F since there was no crop to remove soluble nitrates. Further, the addition of bases from root residues in the Ck treatment may raise the pH to a certain extent.

The relationships of pH with different rates of residue application in respect of cornstalks and alfalfa hay is indicated in Figure 8. While the alfalfa hay plots were supplied with 180 pounds of N per acre as basic manurial dosage, common to all treatments, the cornstalk plots received an additional supply of 20 pounds of N for each ton of residue applied. The difference in the two curves clearly indicates that although cornstalks and alfalfa hay produce similar quantities of organic carbon as explained in previous chapters, the pH level is affected by the difference in the rate of nitrogen application.

The decrease in pH over time is shown in Figure 9. Larson (64) had indicated the soil pH studied in 1957 on 4 different individual plots. As this is the only data available to study the pH effect over time, the pH of the same plots in 1964 are shown here for comparative purposes. The over-all decrease among the plots as well as the decrease during the period is greatest in C_8. Thus, it is clear that the decrease in soil pH takes place continuously over the period of years due to the continuous applications of nitrogenous fertilizers, and the greater the quantity of N applied the faster the decline of soil pH.

D. Corn grain yield

The corn yields obtained for the past 10 years are given in Table 6, and their statistical analyses in Table 24 in the Appendix. The data indicate that except for the years 1961, 1964, and 1965, no significant difference occurred among the

Figure 8. Relationship of soil pH to organic carbon in 0 to 6 inches soil depth.

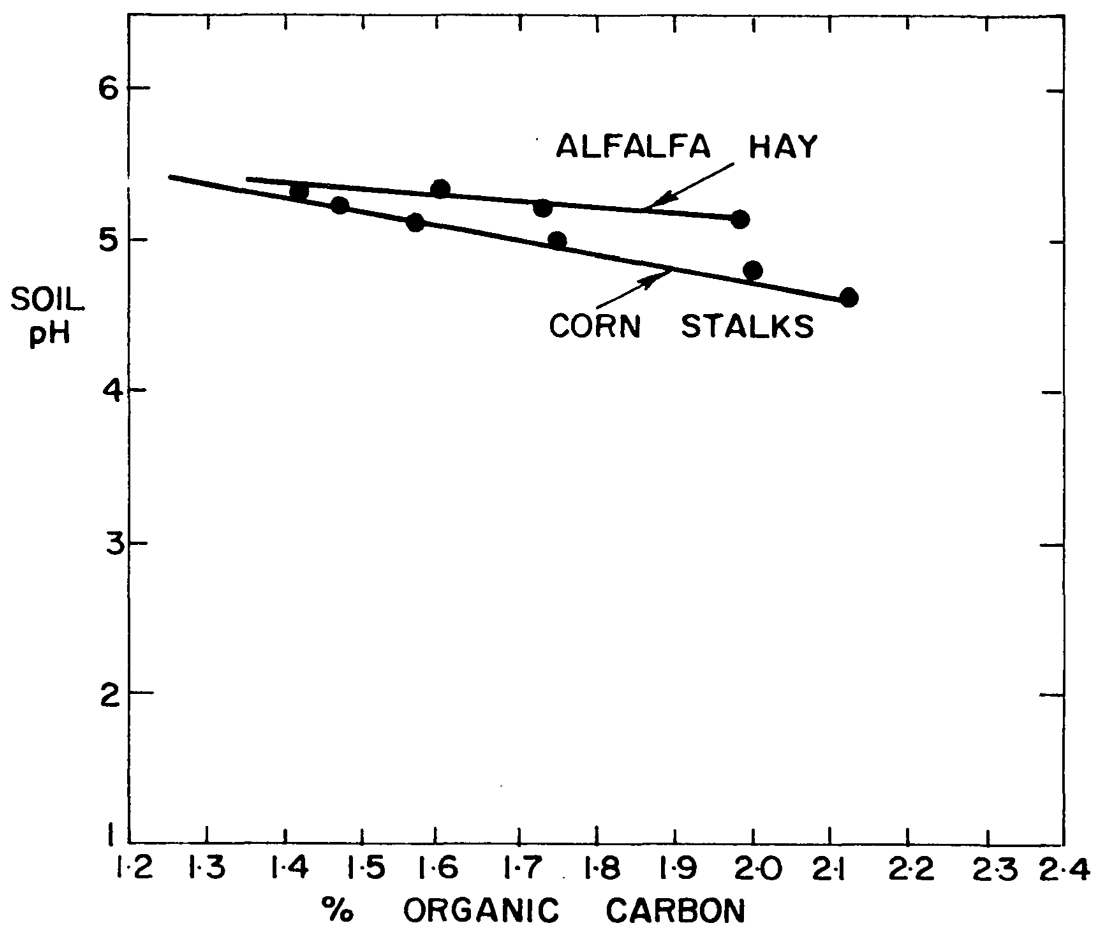
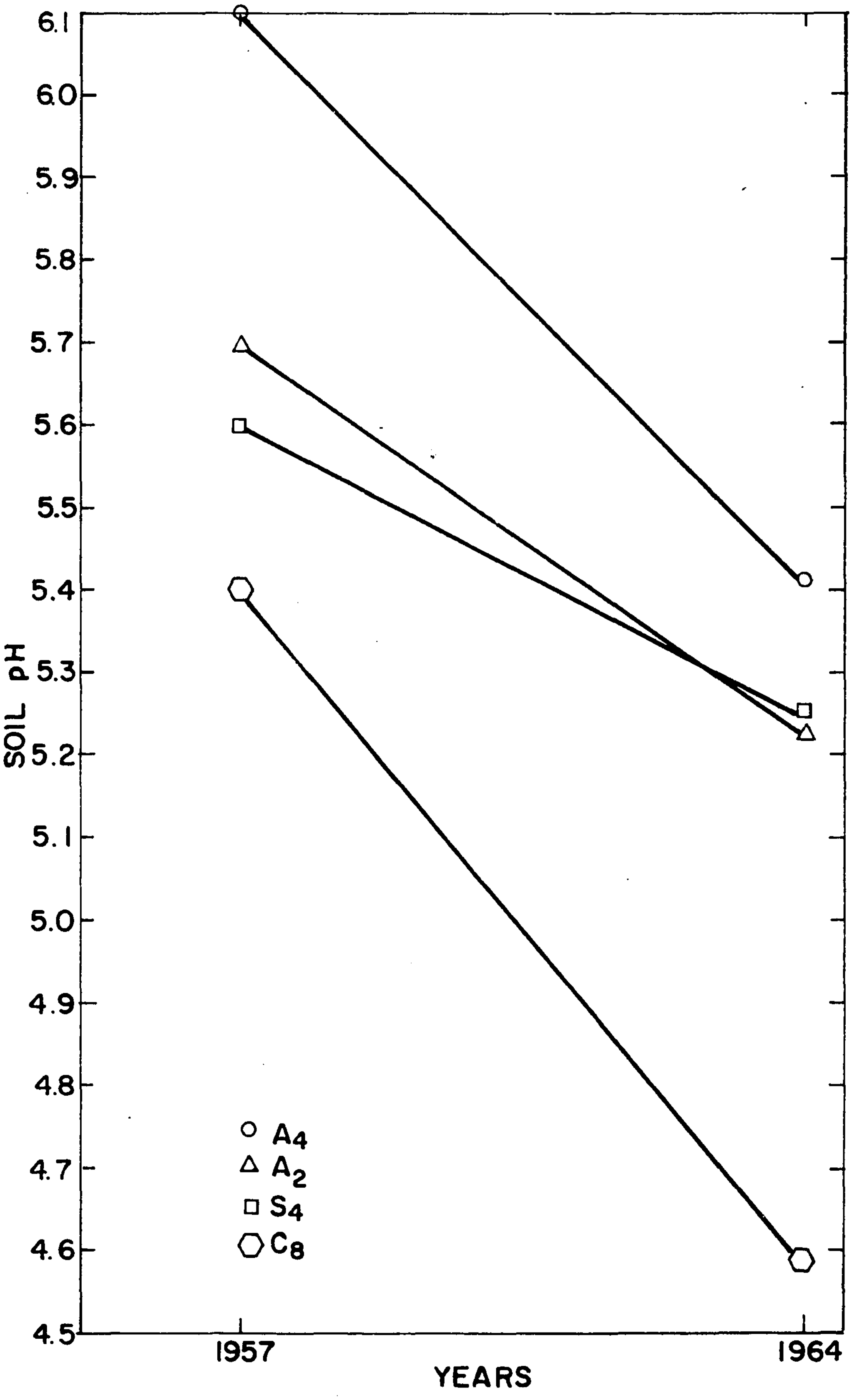

ALFALFA HAY
CORN STALKS
SOIL pH
6
5
4
3
2
1
1·2 1·3 1·4 1·5 1·6 1·7 1·8 1·9 2·0 2·1 2·2 2·3 2·4
% ORGANIC CARBON

Figure 9. Soil pH of four plots for the years 1957 and 1964 as influenced by the application of different types and amounts of organic residues and associated N treatment.



6.1
6.0
5.9
5.8
5.7
5.6
5.5
5.4
5.3
5.2
5.1
5.0
4.9
4.8
4.7
4.6
4.5
SOIL pH
1957
1964
YEARS
A4
A2
S4
C8

Table 6. Yield of corn for the period 1956 to 1965 as influenced by cumulative effects of organic residue application

Tmt. No.	Tmt.	Yield in bushels per acre									
		1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
1	F	-	-	-	-	-	-	-	-	-	-
2	Ck	31.1	73.6	73.3	124.3	123.6	105.3	108.8	119.9	101.2	128.0
3	C_1	45.2	75.1	79.4	120.0	125.6	110.4	111.6	121.5	99.1	128.8
4	C_2	33.8	74.6	76.2	131.9	118.9	111.2	113.1	119.2	92.3	121.6
5	C_{2-2}	30.4	79.6	76.6	131.6	116.4	112.8	105.7	120.2	97.5	127.1
6	C_4	37.8	74.6	76.8	131.0	125.4	112.4	117.6	117.9	89.4	119.6
7	$C_{\underline{8}}$	40.4	66.4	76.9	134.8	122.6	106.3	112.4	112.9	87.0	106.4
8	$C_{\underline{16}}$	43.6	72.1	68.4	130.3	115.3	111.8	110.5	123.5	87.0	117.7
9	C_8	40.4	73.9	78.2	130.9	126.2	118.8	107.0	113.5	86.7	114.6
10	A_1	31.6	73.3	81.1	128.4	129.3	112.6	119.9	125.8	100.6	130.3
11	A_2	33.6	74.1	71.9	125.7	126.0	120.6	119.4	120.0	100.1	125.2
12	A_4	34.6	76.0	76.9	132.2	121.9	112.1	120.1	121.2	99.6	126.0
13	A_8	40.2	70.5	73.3	126.3	123.2	120.4	114.6	119.7	96.1	122.4
14	S_4	47.6	61.1	79.1	123.3	118.0	107.1	110.8	123.8	95.7	123.7

Table 6 (Continued).

Tmt. No.	Tmt	Yield in bushels per acre 1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
15	O_4	41.1	74.5	73.2	128.2	127.1	118.1	117.8	116.7	100.8	126.9
16	G_4	37.2	69.8	76.3	135.9	119.3	112.2	114.8	121.1	93.2	123.6
17	C_{16}	63.4	67.4	67.7	130.3	124.3	112.8	116.0	134.2	99.6	100.8
F value		0.92	1.19	1.18	1.10	1.46	2.17[a]	1.30	0.54	2.49[a]	3.66[b]

[a]Significance at 5 percent level. Tabular F (0.05) = 1.95.

[b]Significance at 1 percent level. Tabular F (0.01) = 2.56.

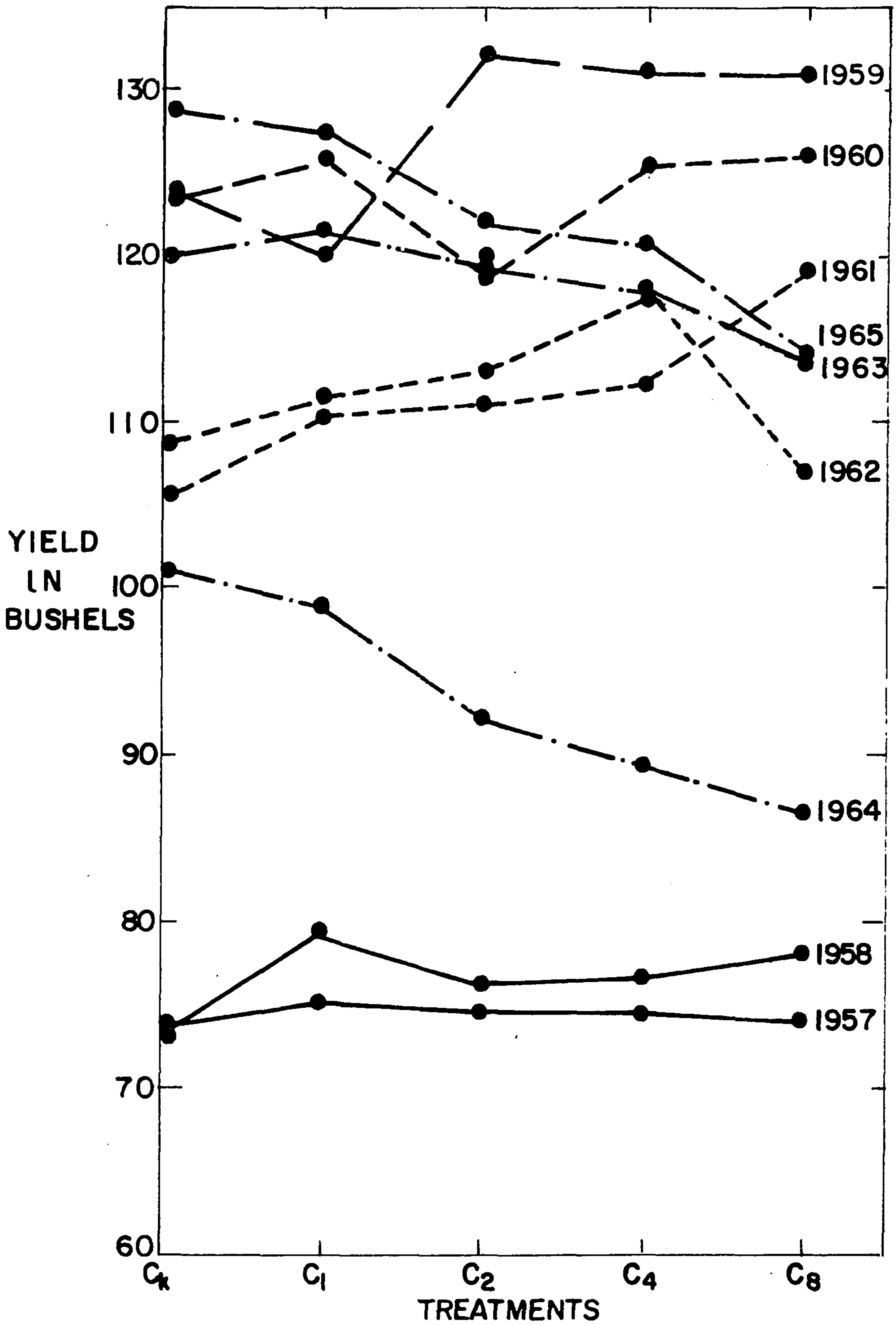
treatments. In the year 1961, the yield trend was favorable for high residue treatments, but consistently lower yields were seen in the high residue plots during the years 1964 and 1965.

The yields, obtained since 1957 to date as influenced by different amounts and different kinds of residue application, are shown in the three graphs separately in Figures 10, 11 and 12. The yields in the previous years (1953 to 1956) were affected by a depression going through the plots that carried run off water from a higher topographical area. In the case of cornstalk application, a definite trend is seen on the yield decline for the years 1963, 1964, and 1965, whereas in the case of alfalfa hay, the decline is seen mostly in 8-ton application.

The decline in yield for the different rates of application for cornstalks and alfalfa hay for the years 1963 to 1965 are shown in Figure 13 by regression lines. The statistical analyses on the regression are shown in Table 25(a) and Table 25(b) in the appendix. These data indicate significant decrease in yield except for the year 1963 for alfalfa hay. The figures also indicate greater decline from 1963 to 1965 in both residues. Thus, there seems to be an adverse accumulated effect on yield associated with the high residue application.

The ineffectiveness of high residues on yield is possible in view of the complex nature of the problem as outlined in Figure 1. However, the adverse effect of the high residue application is interesting.

Figure 10. Corn grain yield for the years 1957 to 1965 as influenced by different amounts of cornstalk application during the years 1953 to 1965.



YIELD
IN
BUSHELS
130
120
110
100
90
80
70
60
1959
1960
1961
1965
1963
1962
1964
1958
1957
C_k
C_1
C_2
C_4
C_8
TREATMENTS

Figure 11. Corn grain yield for the years 1957 to 1965 as influenced by different amounts of alfalfa hay application during the years 1953 to 1965.

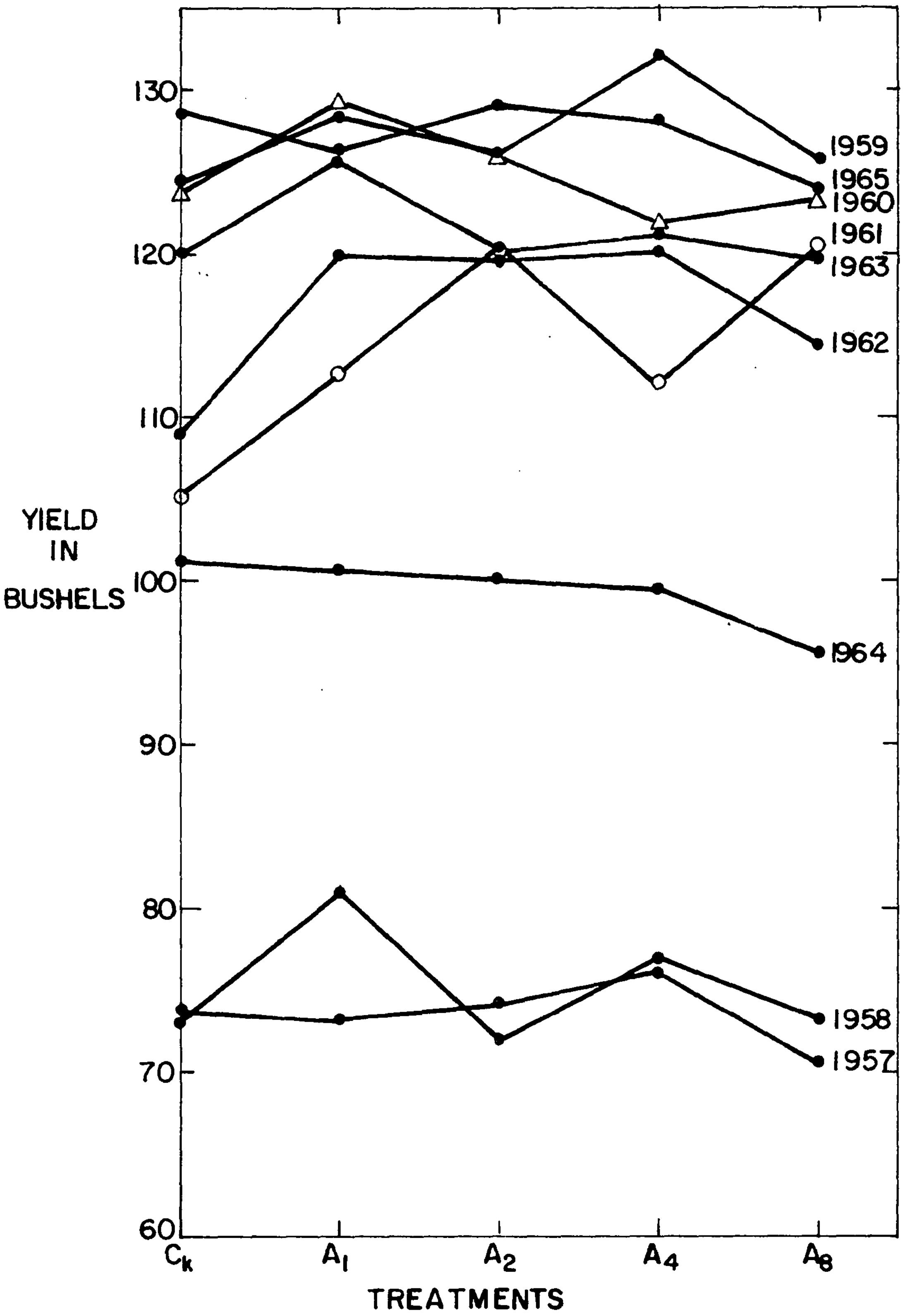

130
120
110
100
90
80
70
60
YIELD
IN
BUSHELS
1959
1965
1960
1961
1963
1962
1964
1958
1957
C_k
A_1
A_2
A_4
A_8
TREATMENTS

Figure 12. Corn grain yield for the years 1957 to 1965 as influenced by application of equal amount of different types of organic residue during the years 1953 to 1965.

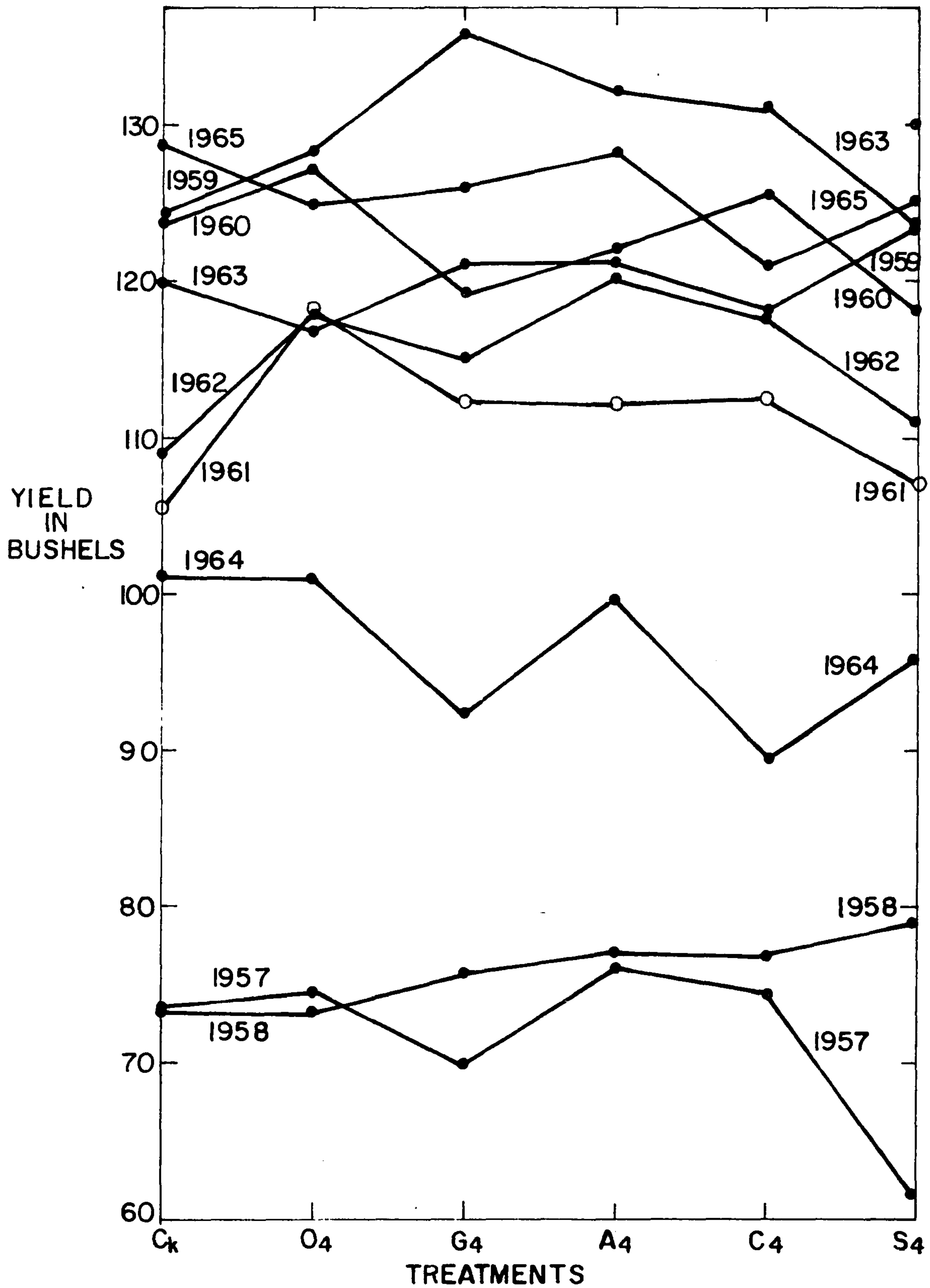
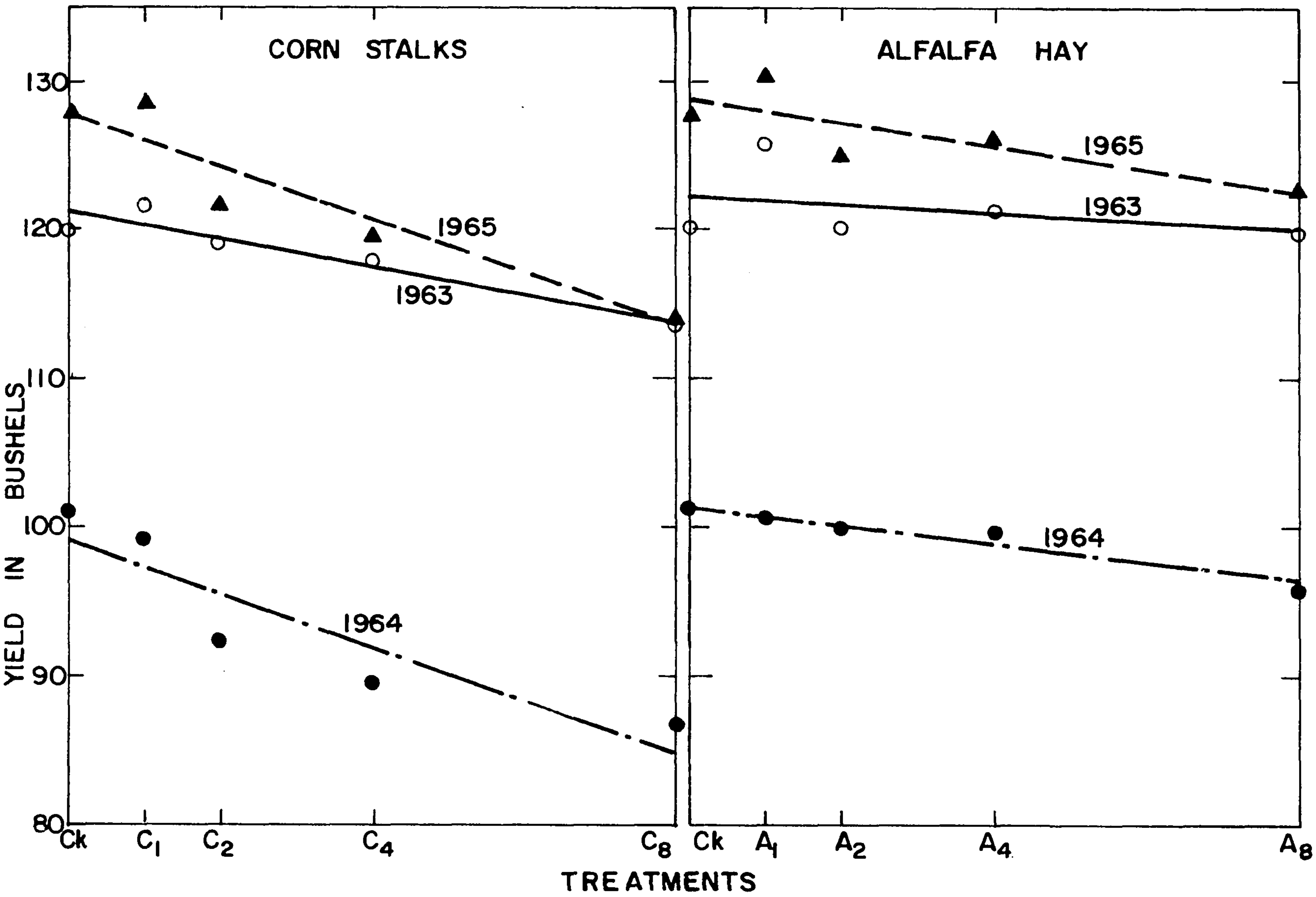

YIELD IN BUSHELS
130
120
110
100
90
80
70
60
1965
1959
1960
1963
1962
1961
1964
1957
1958
1963
1965
1959
1960
1962
1961
1964
1958
1957
Ck
O4
G4
A4
C4
S4
TREATMENTS

Figure 13. Corn grain yield for the years 1963 to 1965 as influenced by different amount of application of cornstalk and alfalfa hay during the years 1953 to 1965.


CORN STALKS
ALFALFA HAY
1965
1963
1964
YIELD IN BUSHELS
130
120
110
100
90
80
Ck
C1
C2
C4
C8
A1
A2
A4
A8
TREATMENTS

In the course of observations of the corn crop for the past 3 years, a definite chlorotic condition in the high residue plots was seen in the early stages of plant growth. The plant height measurements did not show any difference among the treatments. Although these chlorotic conditions later disappeared, the affected plants did not recover fully and as a result, less yield was obtained as shown in Figure 13. Suspecting a possible deficiency of sulphur, the leaves were analyzed for sulphur content in 1964 and sulphur applied to half of each plot in 1965, but this produced no improvement. The analysis of sulphur in leaves as reported by Larson (64) and yield obtained in sulphur-treated plots are given in Table 7. Again leaves were collected in 1965 when the plants were about 80 cm. in height and analyzed for major and micro elements and the data is given in Table 8.

The results did not show any nutrient deficiency in the residue treatments as compared to the check. However, certain interesting information on nutrient uptake was noticed.

The leaf analysis in respect of N, P, K, and Ca for the treatments Ck, C_2, C_8, A_2, and A_8 are shown in Figure 14(a) and Figure 14(b).

In the figure indicating N percent, the uptake is greater in the residue treatments as compared to the check and increase with residue application to a maximum in C_8. Among the Ck, C_2, and C_8 plots, the uptake of N increases with the pattern of N application. But in the Ck, A_2 and A_8 plots where the N

Table 7. Dry weights and percent sulphur on plants (sampled on 6-25-64) and yield of corn

Treatment	Replicate I	II	III	IV	Av.
	1. Oven dry plant weights (g./10 plants)				
Ck	109	122	146	159	134
A_8	157	208	235	197	200
C_8	64	99	120	118	100
	2. Percent sulphur				
Ck	0.27	0.26	0.24	0.25	0.25
A_8	0.24	0.23	0.22	0.23	0.23
C_8	0.27	0.25	0.24	0.23	0.25

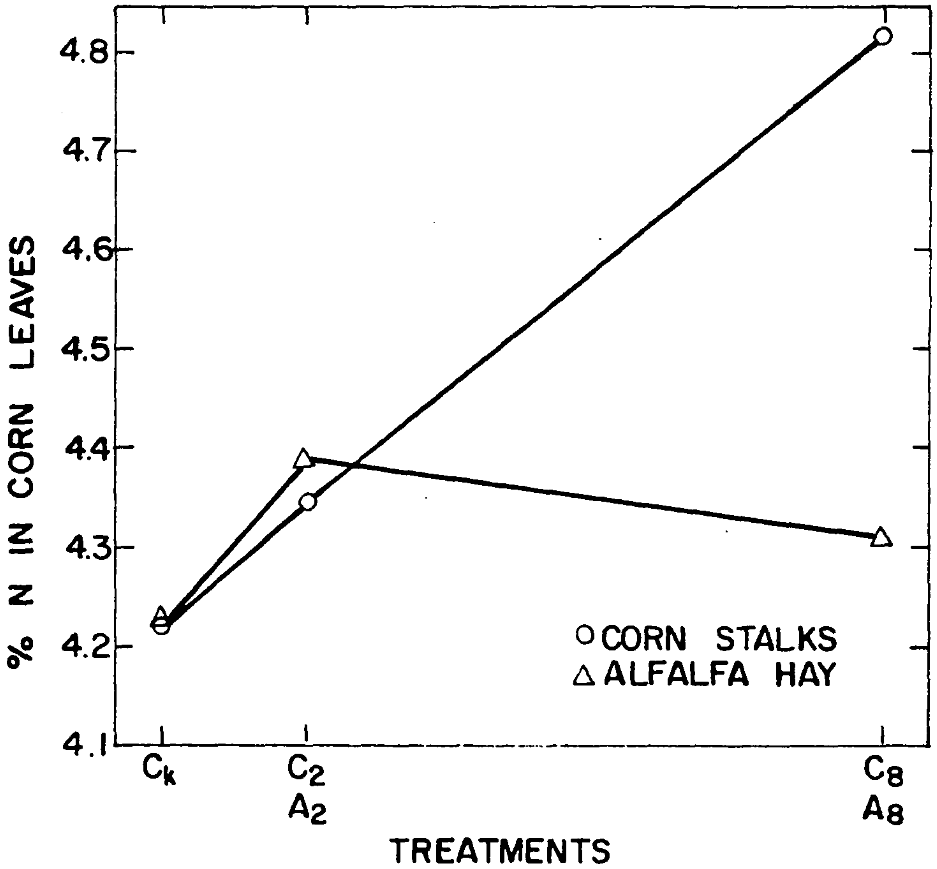
3. Yield of corn in bushels (1965)

	Yield	Plant population
Average yield of sulphur treated plots	123.3	14176
Average yield of non-sulphur treated plots	122.3	14150

Table 8. Corn leaf analysis for major and micro elements (plant heights--65 to 95 cm.--sampled on 6-15-65)

Tmt	N	P	K	Ca	Mg	Mn	Fe	B	Cu	Zn	Al	Sr	Mo	Si
	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%
Ck	4.22	0.33	3.55	0.35	0.17	101	189	18	15	25	114	55	0.79	1.50
C_2	4.35	0.33	3.58	0.32	0.17	99	196	20	11	25	108	56	1.03	1.57
C_8	4.82	0.39	4.56	0.25	0.15	124	188	26	11	31	135	48	0.89	1.67
A_2	4.39	0.34	3.59	0.32	0.17	92	166	18	10	26	101	51	0.81	1.61
A_8	4.31	0.35	3.79	0.33	0.16	86	179	20	8	32	90	53	0.66	1.39
S_4	4.41	0.33	3.83	0.28	0.16	131	196	24	10	28	118	49	0.81	1.77

Figure 14(a). Amount of nitrogen and phosphorous in corn leaves as influenced by the different amounts of cornstalk and alfalfa hay application during the years 1953 to 1965.


% N IN CORN LEAVES
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8
○ CORN STALKS
△ ALFALFA HAY
Ck
C2
A2
C8
A8
TREATMENTS

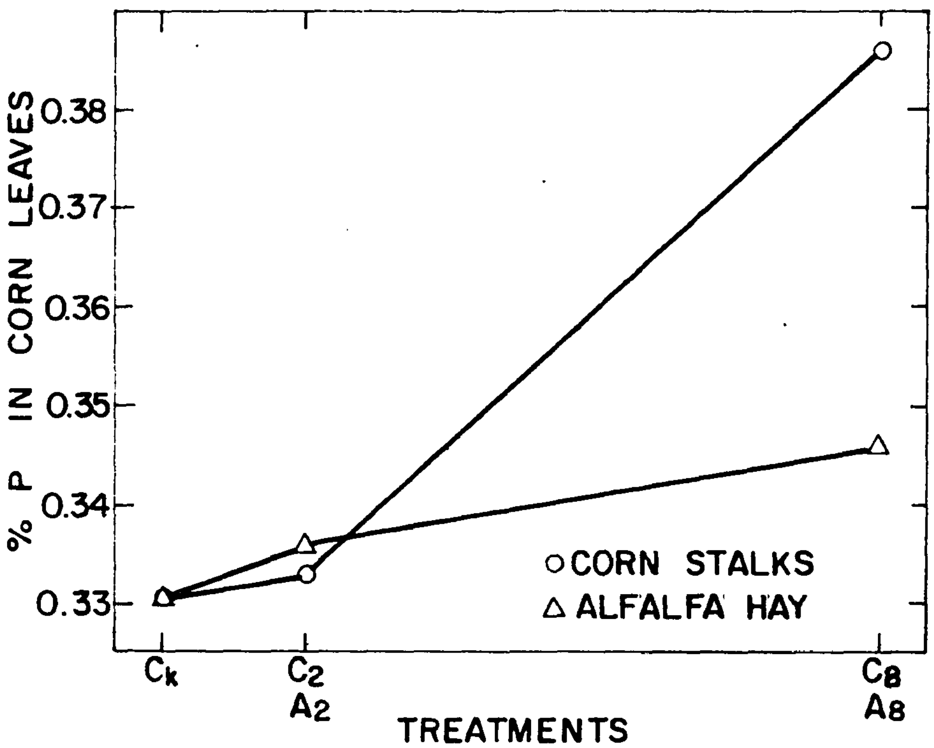
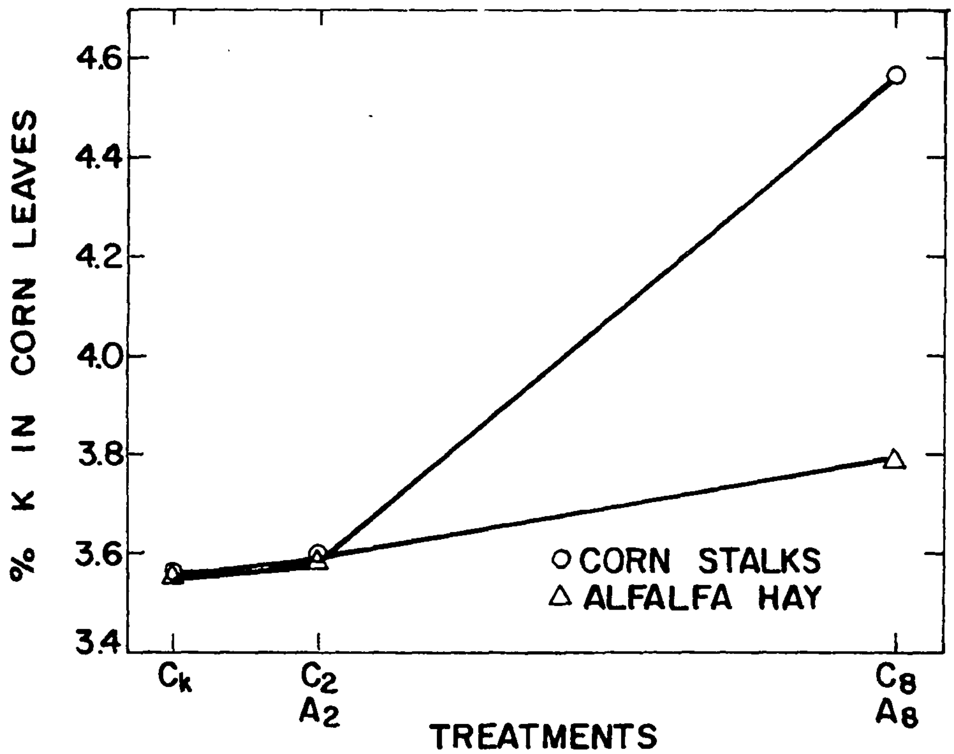
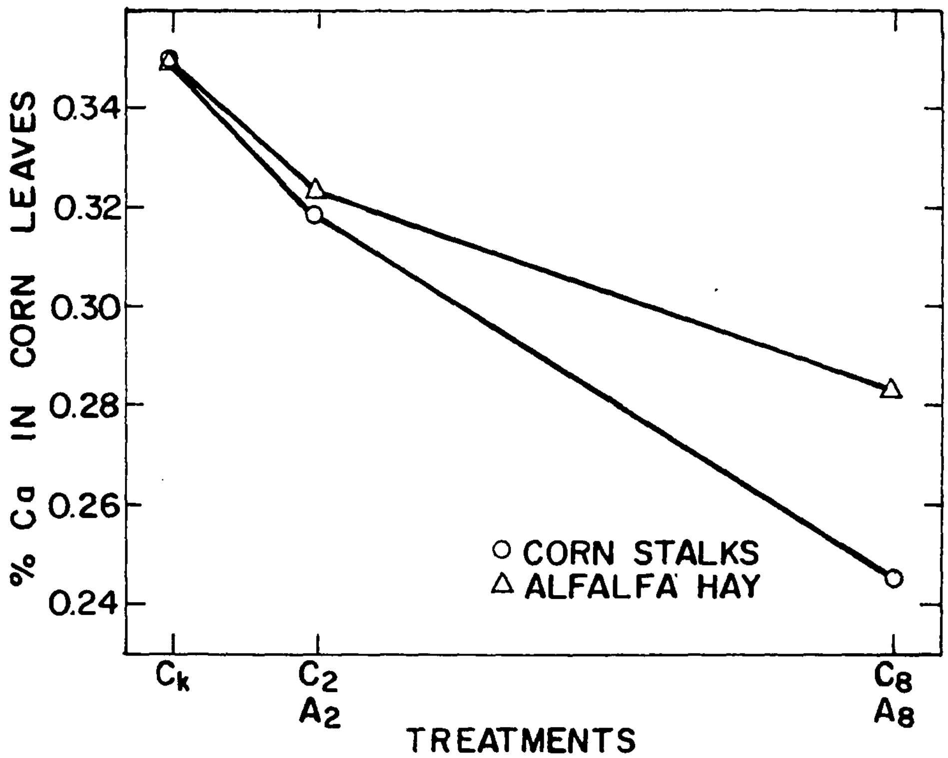

% P IN CORN LEAVES
0.33
0.34
0.35
0.36
0.37
0.38
○ CORN STALKS
△ ALFALFA HAY
Ck
C2
A2
C8
A8
TREATMENTS

Figure 14(b). Amount of potassium and calcium in corn leaves as influenced by the different amounts of cornstalk and alfalfa hay application during the years 1953 to 1965.



4.6
4.4
4.2
4.0
3.8
3.6
3.4
% K IN CORN LEAVES
○ CORN STALKS
△ ALFALFA HAY
Ck
C2
A2
C8
A8
TREATMENTS



0.34
0.32
0.30
0.28
0.26
0.24
% Ca IN CORN LEAVES
○ CORN STALKS
△ ALFALFA HAY
Ck
C2
A2
C8
A8
TREATMENTS

application is the same with differences in residue application only, the uptake of N is only slightly higher in the residue plots than in the check plots. This indicates that the uptake of fertilizer N is greater than the organic N supplied by the alfalfa hay and that the more the quantity of fertilizer N is applied the more is the uptake.

The same pattern of uptake of P and K (with treatments) occurs as for N, with marked increases in uptake between C_2 and C_8, but no real difference between A_2 and A_8. In the case of Ca, the uptake is lowest in C_8.

The trend of increased N percent in corn leaves in response to increased N application follows the general principles of nutrient uptake by plants reported in standard text books such as those written by Russel (109) and Tisdale and Nelson (123). The increase of P percent in a manner similar to N may be due to the well-known principle of addition of one element increasing the percentage of others. Various reasons for the effect of nitrogen on phosphorus uptake were listed by Grunes (44). These include the effect of nitrogen on root and top growth and their effect on phosphorus solubility and availability.

The effects of high acidity or low pH in a soil result in a shortage of available calcium and an excess of soluble aluminum and manganese (109). The low Ca percent in the leaves may be due to this effect.

The increase in K percent may be due to the large addition of K in the residues. But it may also be affected by the phenomena of ionic antagonism. The ratio of uptake of cations between Ca to K and Ca + Mg to K in milliequivalent as cation per 100 g. are given in Table 9.

The data clearly indicate the ion-antagonism between K and Ca as well as K and Ca + Mg. While the percent uptake of K is increased as in the C_8 treatment, the percent uptake of Ca and Mg are decreased.

From the foregoing, it is clear that the nutrient uptake is governed by various factors including high level nutrient application, soil acidity and ion antagonism. These factors have been caused by the high level N applied for the purpose of decomposition of residues and not by the residues themselves. The large difference in N percent of leaves between C_8 and A_8 treatments having almost equal carbon content demonstrates this.

Thus, it is clear that the organic matter has very little influence on the nutrient uptake and their effect seems to be mostly indirect as discussed in the literature review (pages 4 to 11). However, instead of a beneficial effect, there seems to be an adverse effect on the plant growth and yield and the possible causes may be the following:

Table 9. The amounts of calcium, magnesium and potassium in corn leaves as influenced by residue application and associated nitrogen treatment

Tmts.	Ca		Mg		K		Ratio M.E. per 100 g.	
	Per-cent	M.E./100 g.	Per-cent	M.E./100 g.	Per-cent	M.E./100 g.	K/Ca	K/Ca + Mg
Ck	0.348	17.4	0.168	13.8	3.84	98.2	5.6	3.1
C_2	0.318	15.8	0.165	13.6	4.34	111.0	7.0	3.8
C_8	0.245	12.2	0.148	12.2	5.15	131.7	10.8	5.4
A_2	0.323	16.0	0.168	13.8	4.16	106.4	6.7	3.6
A_8	0.330	16.4	0.160	13.2	4.44	113.5	6.9	3.8

1. The low pH may effect the shortage of calcium and excess of soluble aluminum and manganese.

2. The effect of ion-antagonism as indicated by Ca-K ratio resulting from low pH and high residue application.

3. The possibility of phytotoxicity created by micro-organisms as indicated in the review of literature may not be ruled out.

Thus, it can be concluded that on this Marshall soil, the application of large quantities of crop residues over a period of years did not increase the yield of corn; but on the contrary, the cumulative effect of these treatments had an adverse effect in reducing the growth and yield.

E. Aggregate analysis

A complete quantitative characterization of soil structure would involve evaluation of the size and shape of the structural units, the strength of the interparticle bonds within and between units and the size distribution and continuity of pore spaces within and between units. The structure of the soil as a whole involves a summation of these characteristics. Soil structure is therefore a complex phenomenon that cannot be characterized precisely by a single physical measurement (12).

To determine the effect of organic matter on soil aggregation, the following characteristics were studied:

1. Aggregate size distribution by dry sieving

2. Aggregate size distribution and stability by wet sieving
3. Stability of compressed aggregates
4. Aggregate rupture stress and strain
5. Soil bulk density
6. Soil moisture retention, and
7. Withstanding pressure of aggregates

1. Aggregate size distribution by dry sieving The percentage by weight of different aggregate sizes obtained by dry sieving for the depths 0 to 3 and 3 to 6 inches are given in Figures 15 and 16 for treatments F, Ck, C_8 and A_8. The size distribution for all the treatments are given in Tables 10(a) and 10(b).

In comparing the distribution between the two depths, it is seen that the <2 mm. size group is higher and the >9 mm. size group is lower within a treatment in the 0 to 3 inch than the 3 to 6 inch depth. It is also seen that in both depths the lowest percentage group is the 2 to 3 mm. size with a gradual increase in percentage through the 3 to 5 and 5 to 9 mm. sizes. The inference of this pattern of distribution is discussed in the chapter on the theory of aggregate formation.

The aggregate size distribution shows little difference among the various treatments in both depths. To evaluate the treatments, a single parameter to represent the soil was found desirable.

Figure 15. Percentage by weight of soil aggregate size groups in 0 to 3 and 3 to 6 inches depth in fallow and check treatments.

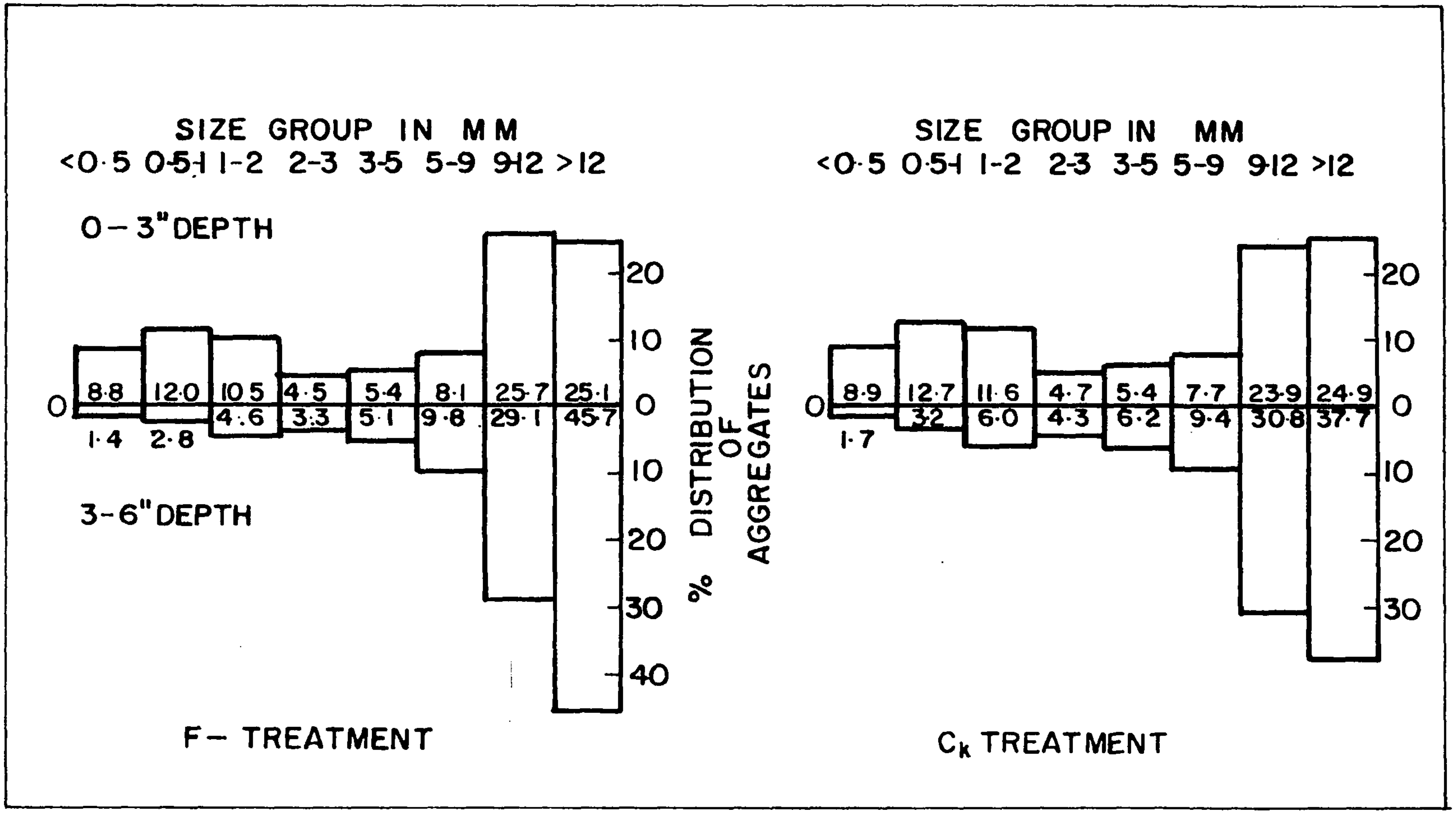

SIZE GROUP IN MM
<0·5 0·5-1 1-2 2-3 3-5 5-9 9-12 >12
0 – 3" DEPTH
3 - 6" DEPTH
8·8 12·0 10 5 4·5 5·4 8·1 25·7 25·1
1·4 2·8 4·6 3·3 5·1 9·8 29·1 45·7
20 10 0 10 20 30 40
% DISTRIBUTION OF AGGREGATES
F– TREATMENT
SIZE GROUP IN MM
<0·5 0·5-1 1-2 2-3 3-5 5-9 9-12 >12
8·9 12·7 11·6 4·7 5·4 7·7 23·9 24·9
1·7 3·2 6·0 4·3 6·2 9·4 30·8 37·7
20 10 0 10 20 30
Ck TREATMENT

Figure 16. Percentage by weight of soil aggregate size groups in 0 to 3 and 3 to 6 inches depth in C_8 and A_8 treatments.

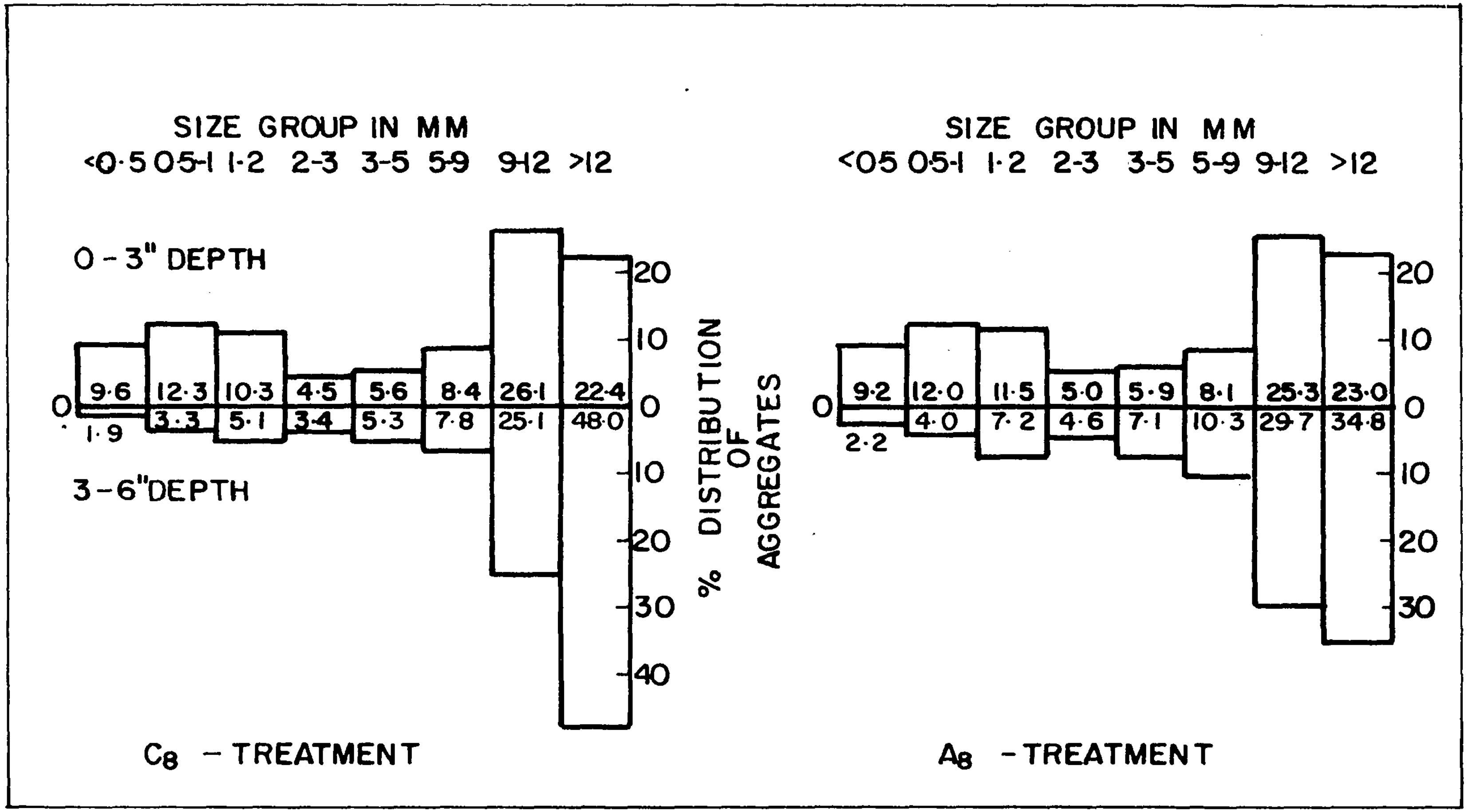

SIZE GROUP IN MM
<0·5 0·5-1 1·2 2-3 3-5 5-9 9-12 >12
0 - 3" DEPTH
3 - 6" DEPTH
9·6 12·3 10·3 4·5 5·6 8·4 26·1 22·4
1·9 3·3 5·1 3·4 5·3 7·8 25·1 48·0
% DISTRIBUTION OF AGGREGATES
C8 - TREATMENT
SIZE GROUP IN MM
<0·5 0·5-1 1·2 2-3 3-5 5-9 9-12 >12
9·2 12·0 11·5 5·0 5·9 8·1 25·3 23·0
2·2 4·0 7·2 4·6 7·1 10·3 29·7 34·8
A8 - TREATMENT

Table 10(a). Soil aggregate size distribution by dry sieving --0 to 3 inches depth

Tmt. No.	Tmt.	% Size groups in mm. <0.5	0.5-1	1-2	2-3	3-5	5-9	9-12	>12
1	F	8.8	12.0	10.5	4.5	5.4	8.1	25.7	25.1
2	Ck	8.9	12.7	11.6	4.7	5.4	7.7	23.9	24.9
3	C_1	8.4	12.0	10.8	4.3	5.3	7.0	23.9	28.1
4	C_2	8.9	12.4	11.5	4.6	5.6	7.9	24.3	24.8
5	C_{2-2}	9.2	12.6	11.0	4.5	5.4	7.8	23.7	25.7
6	C_4	8.4	11.8	11.0	4.5	5.3	7.8	25.5	25.5
7	$C_{\underline{8}}$	8.6	11.6	10.4	4.2	5.0	7.5	24.7	28.0
8	$C_{\underline{16}}$	8.9	12.0	11.1	4.7	5.5	7.7	25.3	24.7
9	C_8	9.7	12.3	10.9	4.5	5.6	8.4	26.1	22.4
10	A_1	7.6	11.0	10.3	4.5	5.7	7.6	26.8	26.6
11	A_2	8.6	12.2	10.3	5.3	5.2	7.6	25.1	25.6
12	A_4	10.3	13.7	11.9	4.7	5.5	7.9	24.4	21.5
13	A_8	9.2	12.0	11.6	5.0	5.9	8.1	25.3	23.0
14	S_4	8.9	12.9	11.7	4.8	5.4	7.8	25.4	23.1
15	O_4	8.9	12.4	11.4	4.7	5.5	8.1	26.7	22.3
16	G_4	9.6	13.0	11.4	4.8	5.6	8.2	26.6	20.8
17	C_{16}	7.2	8.7	8.0	3.6	4.8	6.9	22.7	38.1

Table 10(b). Soil aggregate size distribution by dry sieving 3 to 6 inches depth and addition of 0 to 3 and 3 to 6 inches of 0.5 to 12 mm. size groups

Tmt. No.	Tmt.	% Size groups in mm.								Total of 0-3" and 3-6" for 0.5 to 12 mm.
		<0.5	0.5-1	1-2	2-3	3-5	5-9	9-12	>12	
1	F	1.4	2.8	4.6	3.3	5.1	8.0	29.1	45.7	64.25
2	Ck	1.9	3.8	6.0	4.3	6.2	9.4	30.8	37.7	71.84
3	C_1	1.6	3.2	5.3	3.7	5.7	8.4	26.5	45.8	65.74
4	C_2	2.1	3.9	6.0	4.0	6.0	8.9	28.1	40.9	70.87
5	C_{2-2}	1.9	3.5	5.7	3.9	6.0	9.0	28.0	42.2	69.53
6	C_4	1.8	3.5	5.7	3.9	5.9	8.5	29.0	41.6	68.05
7	$C_{\underline{8}}$	1.7	3.1	5.1	3.5	5.3	8.1	26.2	46.9	64.03
8	$C_{\underline{16}}$	2.5	4.2	6.5	4.4	6.6	9.7	30.2	35.9	72.42
9	C_8	1.9	3.3	5.1	3.4	5.3	7.8	25.1	48.0	66.84
10	A_1	2.0	3.7	5.7	3.9	6.1	9.4	33.9	35.3	67.71
11	A_2	2.1	4.1	6.7	4.4	6.6	9.6	29.9	36.6	72.07
12	A_4	2.0	3.7	6.2	4.6	6.6	9.3	28.6	39.1	73.94
13	A_8	2.3	4.0	7.2	4.6	7.1	10.3	29.7	34.8	75.79
14	S_4	1.7	3.4	5.4	3.7	5.6	8.6	28.0	43.7	69.21

Table 10(b)(Continued).

Tmt.	Tmt.	% Size groups in mm.								Total of 0-3" and 3-6" for 0.5 to 12 mm.
		<0.5	0.5-1	1-2	2-3	3-5	5-9	9-12	>12	
15	O_4	2.1	3.9	6.1	4.1	6.3	9.4	32.1	36.0	71.83
16	G_4	2.3	4.2	6.2	4.0	6.0	8.8	28.6	39.9	72.13
17	C_{16}	1.2	2.3	3.9	2.7	4.6	7.8	23.6	54.0	53.26

Mazurak (73) suggested that the geometric mean diameter (GMD) be used as an index of the aggregate-size distribution. The geometric mean diameter is calculated approximately by the equation

$$\text{GMD} = \exp \frac{\sum_{i=1}^{n} W_i \log \bar{x}_i}{\sum_{i=1}^{n} W_i}$$

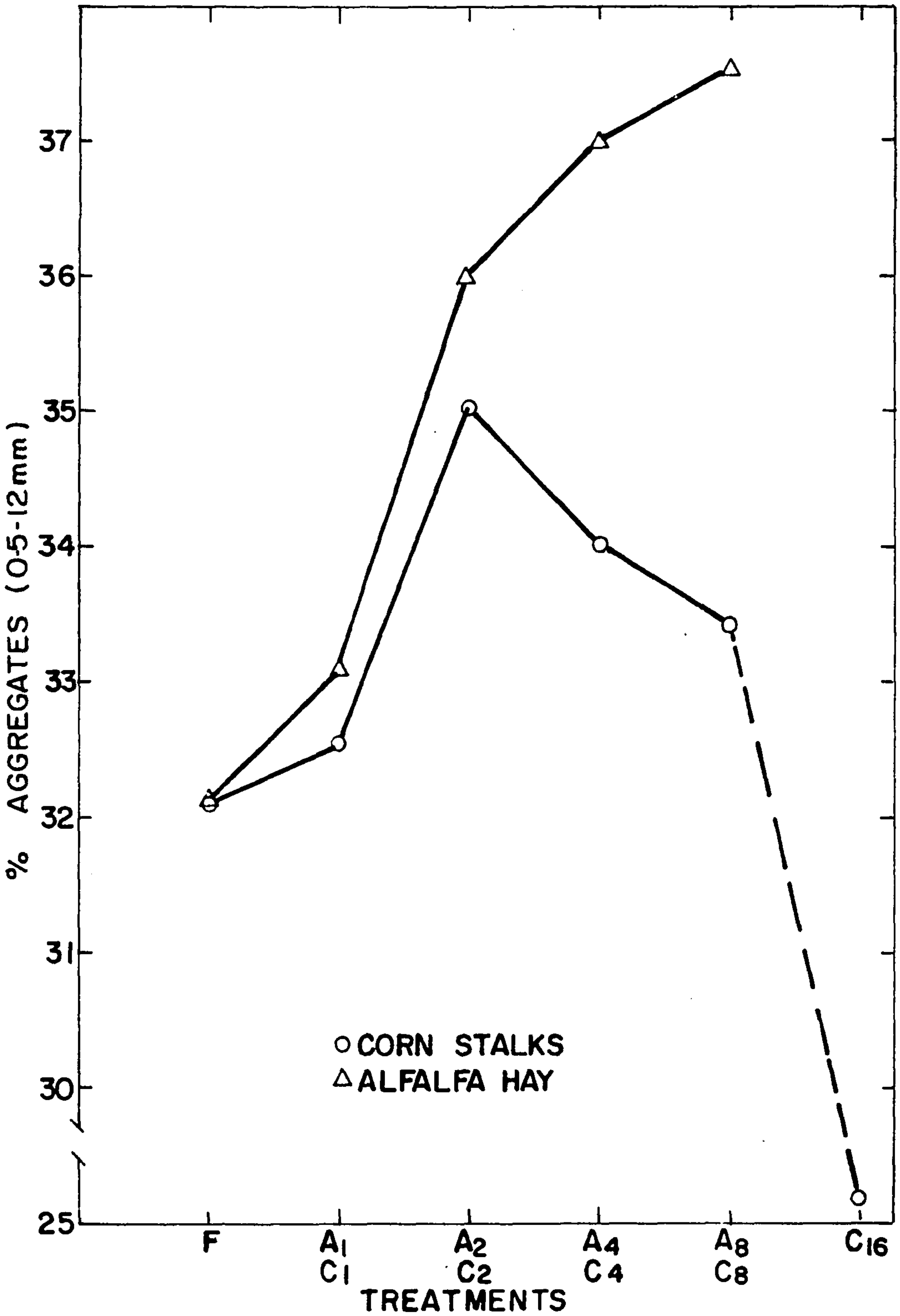
where W_i is the weight of aggregates in a size class with an average diameter $\bar{x}_i$ and $\Sigma_{i=1}^{n} W_i$ is the total weight of the sample. The use of the GMD is supported by Gardner's (40) finding that the aggregate-size distribution in most soils is approximately log-normal rather than normal. This log-normal distribution allows the description of the actual aggregate-size distribution of most soils with two parameters, the geometric mean diameter and the log standard deviation (59). The main disadvantage of expressing data in terms of the GMD and log standard deviation is the extensive work involved in calculating them. The log standard deviation must be obtained by either graphical or differential interpolation from the data.

Allmaras, et al. (3) estimated aggregate size distribution by estimating (a) the logarithm of geometric mean diameter (log GMD) and (b) an index of the dispersion of the aggregate diameters (σ log d). The two parameters were computed mathematically.

For the purpose of the present study, the procedure of Allmara's et al. (3) was followed due to the availability of computing facilities. The data on the logarithm of geometric mean diameter (log GMD) and the dispersion of the aggregate diameters indicate no significant difference among the treatments. To determine further possible differences in aggregate size distribution, the aggregate percentage for each size was added for both depths. The percent by weight of aggregate size between 0.5 to 12 mm. with respect to increasing amounts of cornstalks and alfalfa hay is given in Figure 17 and Table 10(b). The graph shows that the percent by weight of aggregation increased with the quantity of residue application over the entire range of application of alfalfa but decreased in the case of cornstalks above the two ton application. This difference may be attributed to differences in the composition of organic residues.

McHenry (78) reported that undecomposed organic material in the form of ground cornstalks and alfalfa hay act as a diluent in aggregation. He prepared aggregates from a puddled mixture by adding organic materials to samples of clay and sand and wetting and drying them five times. When the organic material was decomposed by incubation, aggregation occurred and he concluded that for the organic matter to act as an active agent of aggregation, decomposition must occur. This view has been confirmed by many workers such as Stallings (117), Russel (109) and others.

Figure 17. The percentage by weight of soil aggregates between 0.5 to 12.0 mm. as influenced by different rates of cornstalk and alfalfa hay applications.


% AGGREGATES (0.5-12 mm)
37
36
35
34
33
32
31
30
25
F
A1
C1
A2
C2
A4
C4
A8
C8
C16
TREATMENTS
CORN STALKS
ALFALFA HAY

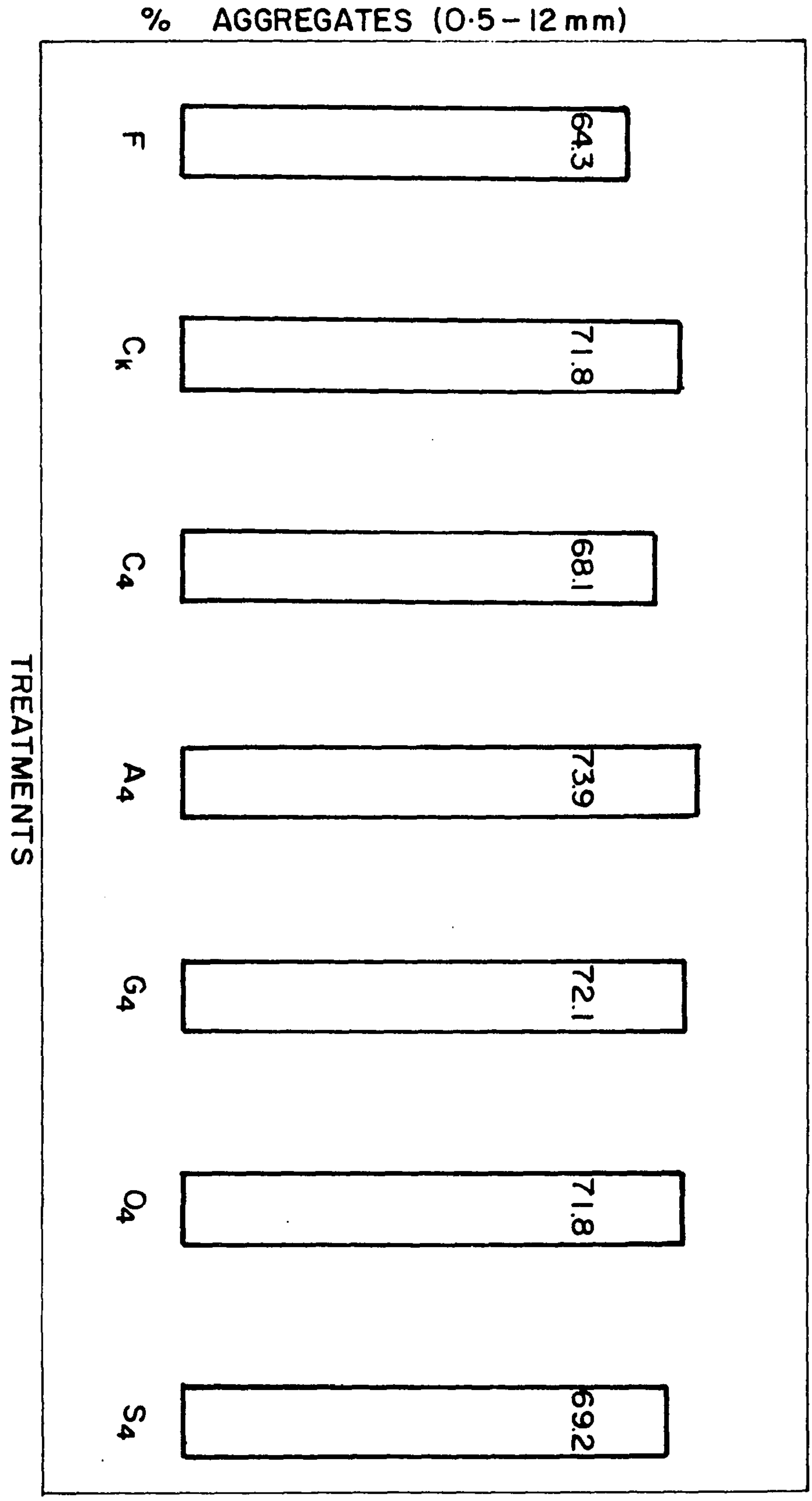
Thus, the difference in the aggregation between cornstalks and alfalfa hay may be due to the undecomposed organic residues. It is of interest to note the close resemblance of Figure 17 to Figure 3 wherein the undecomposed organic residues was indicated.

The aggregate size distribution with equal quantities of residue application is shown in Figure 18. The influence of root residues and crop growth is shown by the lower aggregation in the fallow plot as compared to others. The influence of dilution effect of undecomposed residues is seen by the lower percent of aggregates in C_4 and S_4. Thus, it is likely that the size of aggregates are affected by the type of residues applied.

Direct dry sieving of soils as they occur in the field has been used by Keen (58), Cole (28) Chepil (26), Mazurak (73) and others to evaluate the distribution of clods and aggregates. Baver (7) agreed that dry sieving of soils in the field has considerable merit under certain experimental conditions.

The results indicate that while the decomposed organic material along with root pressure has more influence in increasing the percent of aggregates in the larger sizes, the undecomposed residues have the opposite effect.

Figure 18. The percentage by weight of soil aggregates between 0.5 to 12.0 mm. as influenced by equal amounts of different organic residues application.



% AGGREGATES (0·5 – 12 mm)
TREATMENTS
F
64.3
C_k
71.8
C_4
68.1
A_4
73.9
G_4
72.1
O_4
71.8
S_4
69.2

2. Aggregate size distribution and stability by wet sieving The wet sieving procedure of aggregate analysis evaluates, in part, the size distribution of the structural units and, in part, the stability of the units under the treatments employed.

The size distribution of aggregates by wet sieving with respect to size groups <0.5, 0.5 to 1.0, 1.0 to 2.0, 2.0 to 3.0, 3.0 to 5.0, and 5.0 to 8.0 mm. is shown in Table 11. The differences among the treatments is primarily in the size groups 5.0 to 8.0 mm. and <0.5 mm. The percent by weight of the 5.0 to 8.0 mm. size group is 12.8 in F. It increased to 29.6 in C_8, 26.3 in A_8, 66.8 in C_{16} and 84.2 in continuous meadow. This indicates the effect of organic matter and other forces such as root pressure for aggregation. Similarly, the size group <0.5 mm. accounts for 26.2 percent in F, 18.1 percent in C_8, 15.2 percent in A_8, 10.5 percent in C_{16} and only 1.6 percent in continuous meadow. The influence of residues is not demonstrated clearly among the size groups between <0.5 and 5.0 to 8.0 mm.

It is of interest to note that the percentage distribution of the size groups follow closely the distribution pattern found in the dry sieving. The size group 2.0 to 3.0 mm. is generally of lowest percent among the different groups after a gradual decline from the bigger groups and later increasing to a uniform percent of about 20 in the 1.0 to 2.0 mm. size. Detail discussion on the inference of this pattern

Table 11. Soil aggregate size distribution by wet sieving (5 to 8 mm. aggregates) from 0 to 6 inches depth

Tmt. No.	Tmt.	% Size groups in mm. 5-8	3-5	2-3	1-2	0.5-1	<0.5	Total of 1-8 mm.
1	F	12.8	5.6	10.6	20.3	24.5	26.2	49.3
2	Ck	19.1	6.9	7.6	16.8	24.4	25.2	50.4
3	C_1	15.0	10.1	9.4	20.8	24.5	20.2	55.3
4	C_2	21.1	10.1	10.0	20.1	21.6	17.1	61.3
5	C_{2-2}	21.8	8.5	9.4	20.0	21.3	19.0	59.7
6	C_4	17.1	6.6	7.3	19.0	25.5	24.5	50.0
7	$C_{\underline{8}}$	16.5	9.5	9.3	21.1	22.2	21.4	56.4
8	$C_{\underline{16}}$	17.7	11.3	9.7	21.5	21.4	18.4	60.2
9	C_8	29.6	7.1	8.2	17.9	19.1	18.1	62.8
10	A_1	10.6	7.4	8.3	21.7	28.6	23.4	48.0
11	A_2	8.8	7.5	10.3	22.5	28.7	22.2	49.1
12	A_4	22.7	10.8	9.9	19.6	18.5	18.5	63.0
13	A_8	26.3	9.3	9.2	18.4	21.6	15.2	63.2
14	S_4	22.0	7.6	8.5	20.0	21.7	20.2	58.1
15	O_4	34.9	9.1	8.1	15.9	16.5	15.5	68.0
16	G_4	21.0	8.0	8.4	14.1	25.9	22.6	51.5
17	C_{16}	66.8	10.0	3.2	6.5	3.0	10.5	86.5
18	Cont. meadow	84.2	4.8	2.9	3.8	2.7	1.6	95.7

is discussed in the chapter on the theory of aggregate formation.

The effect of organic residues in increasing aggregate formation has been reviewed previously. However, its effect in increasing the aggregate size is indicated here. Browning (23) reported that a single application of organic matter, when added to soils containing only a small amount of cementing materials necessary for the formation of stable aggregates, increased the number of large aggregates. Stauffer (118) found that mulch favored the formation of large aggregates. Baver (7) reported that organic matter is conducive to the formation of relatively large stable aggregates. The results here clearly indicate that organic matter is conducive for large stable aggregates.

The total stability of aggregates of the size >1.0 mm. in the different treatments is shown in Table 12. The curve representing total stability of the above size is shown in Figure 19 (Curve 1).

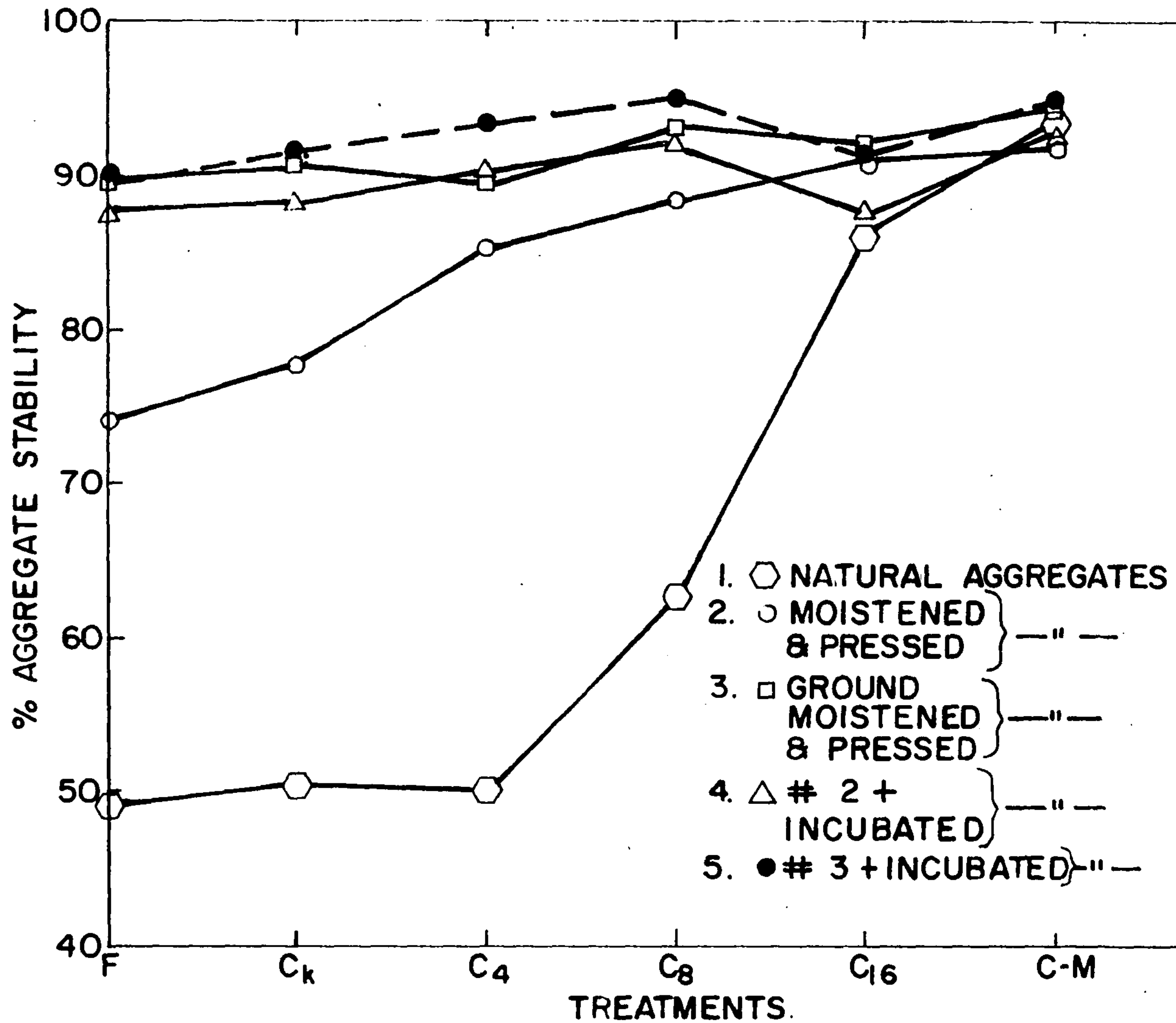
The data indicates that the stability of aggregates ranges from 49.3 percent in F and 95.7 percent under continuous meadow. Although there is no difference among F, Ck and C_4 the increased stability under C_8, A_8 and C_{16} clearly indicates the stability in high residue application. Thus, the high residue application not only increases the size but also the stability.

Table 12. Soil aggregate stability under different treatments (percent stability of 1 to 8 mm. aggregates by wet sieving)

Tmt. No.	Tmt.	Natural aggregates (1)	Moistened pressed broken and air-dried (2)	Powdered moistened pressed broken and air-dried (3)	(2)+ Incubated before air drying (4)	(3)+ Incubated before air drying (5)
1	F	49.3	74.1	90.0	87.9	90.3
2	Ck	50.4	77.8	90.8	88.1	91.7
3	C_4	50.0	85.3	89.7	90.1	93.8
4	C_8	62.8	88.4	93.2	92.2	95.1
5	C_{16}	86.5	91.1	92.1	87.7	91.6
6	A_2	49.1	75.5	91.1	91.5	92.6
7	A_8	63.2	83.9	93.2	89.2	92.7
8	G_4	51.5	82.1	90.2	94.0	92.1
9	C.M[a]	95.7	92.1	94.5	92.8	94.9

[a]C.M--From continuous meadow adjoining experimental plots.

Figure 19. Soil aggregate stability (more than 1.0 mm.) of F, Ck, C_4, C_8, C_{16} and continuous meadow treatments prepared artificially under different procedures and compared to natural aggregates.



100
90
80
70
60
50
40
% AGGREGATE STABILITY
F
C_k
C_4
C_8
C_{16}
C-M
TREATMENTS
1. NATURAL AGGREGATES
2. MOISTENED & PRESSED —"—
3. GROUND MOISTENED & PRESSED —"—
4. # 2 + INCUBATED —"—
5. # 3 + INCUBATED —"—

Colloidal organic matter was found to be more effective than equal amounts of colloidal clay in stabilizing aggregates (32). Robinson and Page (105) attributed the major role in aggregate stability to organic matter. Peerlcamp (92) and Miller and Kemper (82) reported that the increased stability resulting from added organic matter is transient in nature and stability decreases to the original level after a few months. The present study indicates that aggregate stability increased in the high residue treatments (8 and 16 tons) only.

Under normal agricultural practices, the residue available with cornstalks may amount to about 3 tons only. This quantity may not be sufficient to increase the stability of aggregates to an appreciable extent as seen from the result of this experiment.

3. Stability of compressed aggregates The data on the effect of grinding the aggregates and subjecting them to pressure and incubation are given in Table 12. The concerned graphs pertaining to their stability in comparison to natural aggregates are shown in Figure 19.

In case of moistened and pressed aggregates (Curve 2), a smooth curve was obtained, showing increased stability depending on the residue application. However, when compared to the natural aggregates, the sharp increase in all the plots except continuous meadow indicates the effect of pressure combined with wetting and drying in aggregate stability. This curve has clearly brought out the effect of the amounts of organic matter application. The high stability of continuous meadow under natural conditions as well as the moistened and pressed treatment indicate that the aggregates have been subjected to constant root and moisture effects. These combined with other factors would have helped in stability.

The third curve indicating the aggregates subjected to grinding, moisture and pressing increased the stability in all treatments indicating the effect of grinding. This may be due to the coagulation of colloidal particles and cementing together due to pressure. These particles may stick together under the influence of drying-out process and thus become more stable.

The fourth curve shows the effect of moisture, pressure and incubation, and clearly brings forth the effect of incubation on stability. This difference is seen when compared to curve 2, the treatments of which are the same except for incubation. However, the stability is less than curve 3 indicating that grinding the aggregate has more effect in stability.

The fifth curve, the treatments of which include grinding, moisture, pressure and incubation shows the maximum stability in all treatments making the effect of organic residues of little importance. However, the effect of organic matter is still visible when the treatments F, Ck, C_4 and C_8 are compared. The decrease in C_{16} may be due to the dilution effect of the undecomposed material present.

The soil colloidal material is responsible for the cementation of primary particles. This colloidal material includes among others clay particles themselves and organic colloids. Baver (7) reported that at higher percentages of organic matter, the effect of clay in secondary particle formation becomes insignificant and that the effect of organic matter is less significant in soils containing large amounts of clay.

The soils in this experiment contains 34.6 percent clay as shown by Latif (65). The clay particles may function as a binding agent themselves in aggregate formation (60). The liquid bonds supplied by moisture are extremely important in the cohesion between clay particles for the function of aggregates. Peterson (94) concluded that clay particles orient themselves under wet conditions and as drying occurs, the cohesive force and linkages between particles increase. Thus, additional layer of clay gel may be accumulated on the surface of previously formed aggregates, building up larger stable aggregates.

Thus it is likely that the cohesive forces between oriented clay particles combined by dehydration would have caused the increased aggregation in all the plots including fallow when the aggregates are moistened, pressed and air-dried.

Activity of root systems together with soil fauna was considered as the primary factor by Zakharov (133). Later Gedroiz (Zakharov, 1927) suggested that aggregate formation is primarily dependent upon pressure and coagulation. This concept has been adopted by Tiulin (124). He conceived that the pressure produced by roots and animals produce more intimate contact between particles, so that the cementing influences of the water films are rendered more effective. Baver (7) concluded that plant roots are as important as any other factor in stable granulation. Thus, the high aggregation in continuous meadow may be explained by root effects combined with organic matter content. The increased aggregation in fallow plot may be due to clay particles acting as binding agents.

Beacher and Strickling (9) found that pressure-treated soil was not as water-stable as field soil aggregates. Their treated aggregates were obtained by extruding soil material through round hole sieve openings at pressures up to several thousand pounds per square inch and the spaghetti-like extruded material dried and broken. Rogowski and Kirkham (107) reported decreased water stability in aggregates subjected to moisture and pressure treatments. The results obtained here indicate that the pressure helped increase the stability in the residue and fallow plots. In the meadow plot where the stability had reached the maximum any further treatment will reduce it. The organic matter content in the different plots ranges from about 2 to 3.4 percent only whereas the soil reported by Rogowski and Kirkham (107) contains 4 percent. Thus, it is possible that under low range of organic matter content, the stability increases with moisture and pressure.

The effect of incubation in increasing aggregate stability emphasizes the role played by microorganisms. The importance of microorganisms in aggregate formation has been reviewed earlier. Stallings (117) while reviewing soil aggregate formation emphasized the importance of biologically active organic matter and the substances produced or synthesized by microorganisms.

Thus it can be concluded that when natural aggregates are subjected to moisture, pressure, grinding and incubation treatments, their water stability can be increased considerably. The effect of organic matter in increasing aggregate stability is more visible when subjected to moisture and pressure treatments.

4. Aggregate rupture, stress and strain Rupture stress (crushing strength) and rupture strain of dry aggregates has been considered as an index of aggregate strength by Rogowski (106). Individual aggregates of the size 3 to 5 mm. were subjected to stress and strain measurements by an apparatus used by Rogowski (106) and the mean rupture strength $\pm$ standard error of the mean have been computed.

The energy value required for rupturing the aggregates is shown in Table 13. The data indicates the energy of rupture while increasing from Ck to C_{16} decreases from F to Ck. Among the residues of equal quantities, S_4 has the lowest and O_4 the highest energy of rupture. This may be due to the composition

Table 13. Energy of rupture (T_r) and standard error values (SE) for the different treatments

Treatments	T_r	$\pm$SE
	x 10^4 ergs./cm.^{2}	
F	3.71	0.74
Ck	3.61	0.51
C_4	4.02	0.58
C_8	4.08	9.34
A_4	3.61	0.48
G_4	3.83	0.51
O_4	4.17	0.65
S_4	3.04	0.48
C_{16}	5.47	0.55

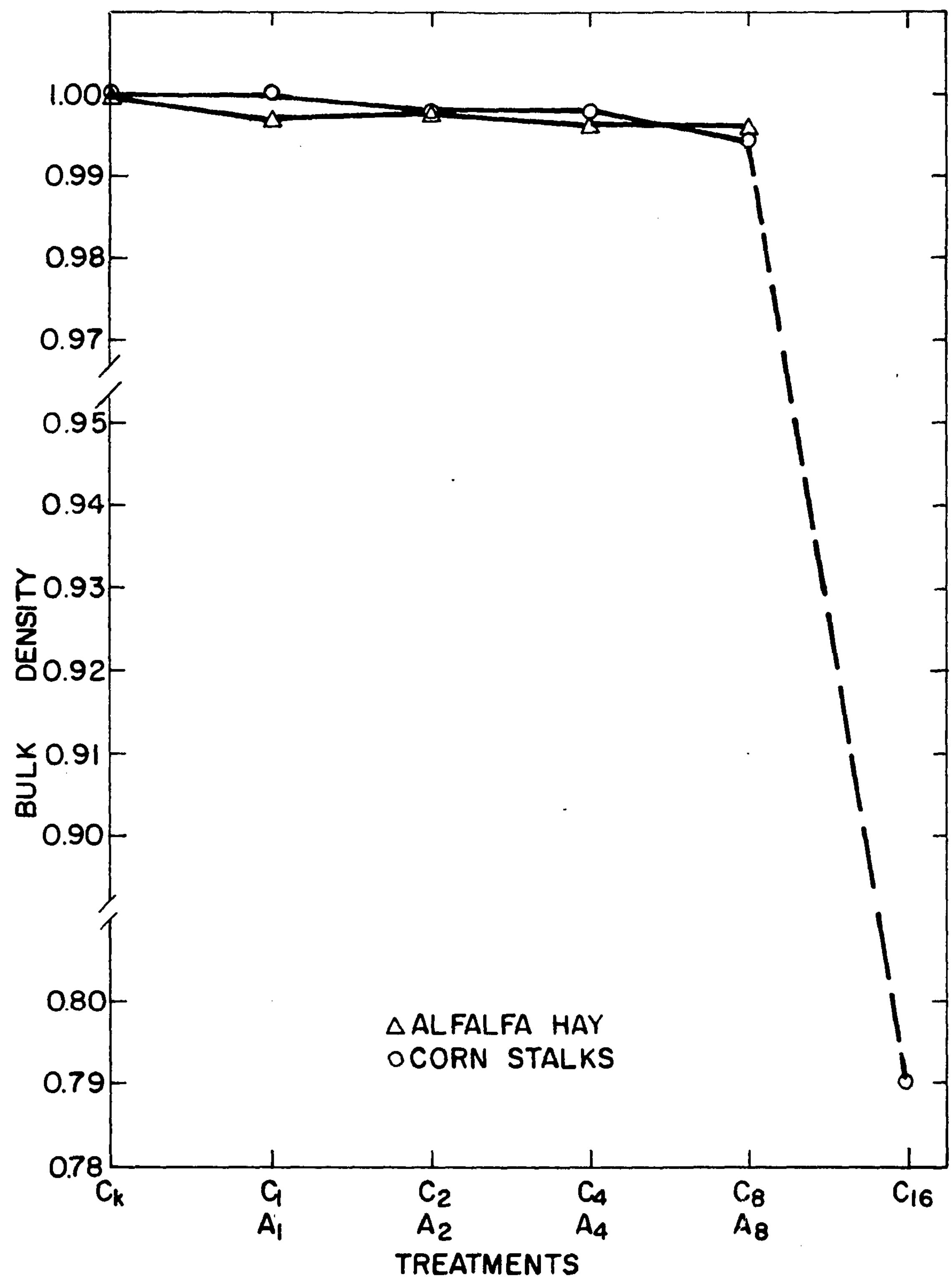
of the residues applied.

Rogowski (106) concluded that one might expect to find stronger soil aggregates at lower carbon content. The results obtained here over a range of different carbon content do not indicate the above conclusion.

Taylor and Gardner (122) found soil strength increased with bulk density. Rogowski (106) reported soil strength to increase with bulk density but to a lesser degree on comparable moisture content. In the data recorded here, the strength in C_{16} was maximum among the treated aggregates, although it had the lowest density. Martinson and Olmstead (72) while indicating no relationship of strength to stability, reported that the factors affecting crushing strength are too many and their interaction too complex for definite interpretation of results. The present study also indicates the complex nature of interaction of different forces leading to aggregate strength.

5. Soil bulk density The bulk density of the soil samples for 0 to 6 inches depth with respect to different rates of residue application are shown in Figure 20. The figure indicates that bulk density decreases as the amount of residue applied increases in both cornstalks and alfalfa hay. The steep fall in bulk density in C_{16} plot is of particular interest since it demonstrates the effect of undecomposed organic residues and large size clods (Tables 2 and 10).

Figure 20. Soil bulk density in 0 to 6 inches depth as influenced by different amounts of alfalfa hay and cornstalk application.


BULK DENSITY
1.000
0.99
0.98
0.97
0.95
0.94
0.93
0.92
0.91
0.90
0.80
0.79
0.78
△ ALFALFA HAY
○ CORN STALKS
C_k
C_1 A_1
C_2 A_2
C_4 A_4
C_8 A_8
C_{16}
TREATMENTS

The bulk density for the two different depths of 0 to 3 and 3 to 6 inches along with the pore space percentage calculated is shown in Table 14. The data brings out the difference between the two depths in bulk density and pore space. While the bulk density ranges from 0.88 to 0.91 in the replicated plots for the depth 0 to 3 inches, it is >1.0 for the 3 to 6 inches depth. The C_{16} plot is distinctly different with 0.77 for 0 to 3 inches and 0.83 for 3 to 6 inches. Similarly the pore space percentage is higher in 0 to 3 inch depth. The data also shows the difference of the two types of residues in their capacity to reduce the bulk density. While the range of difference in bulk density for A_1 through A_8 is 0.027, it is 0.039 for C_1 through C_8 for 0 to 3 inches depth. Within the cornstalk plots, difference is seen between C_1, C_4, C_8 and C_{16}. As the rate of residue application increases, the bulk density is reduced. These differences may not be significant. However, the trend indicates the above possibility.

Although plowing helps decrease of bulk density, the difference between the two depths denotes the more compact nature of the soil in the lower depth. While the bulk density is uniform in most treatments, in 3 to 6 inch depth, a striking difference occurs between fallow with 1.2 and C_{16} with 0.8. The increase in bulk density in fallow plot may be due to the low organic matter content and non-cropping. The effect

Table 14. Bulk density and pore space in the two depths of 0 to 3 and 3 to 6 inches

Tmt. No.	Tmt.	Bulk density 0-3"	Bulk density 3-6"	% Pore space[a] 0-3"	% Pore space[a] 3-6"
1	F	0.90	1.21	66.10	54.20
2	Ck	0.90	1.10	65.95	58.47
3	C_1	0.89	1.11	66.19	58.13
4	C_2	0.90	1.07	66.19	59.67
5	C_{2-2}	0.86	1.09	67.56	58.99
6	C_4	0.88	1.09	66.94	58.88
7	$C_{\underline{8}}$	0.91	1.09	65.74	58.88
8	$C_{\underline{16}}$	0.90	1.08	66.16	59.28
9	C_8	0.85	1.03	67.81	61.14
10	A_1	0.89	1.06	66.24	60.14
11	A_2	0.90	1.06	65.91	60.08
12	A_4	0.88	1.06	66.92	59.95
13	A_8	0.88	1.04	66.59	60.63
14	S_4	0.77	0.82	70.80	68.86
15	O_4	0.89	1.08	66.54	59.34
16	G_4	0.91	1.06	65.78	60.12
17	C_{16}	0.77	0.83	70.80	68.86

[a]% Pore space calculated by using the formula $(1-\frac{Db}{2.65})$ x 100.

of organic matter is clearly visible in the lower bulk density in C_{16} plot in both depths of soil.

Bulk density varies with the structural condition of the soil, particularly that related to packing. For this reason it is often used as a measure of soil structure.

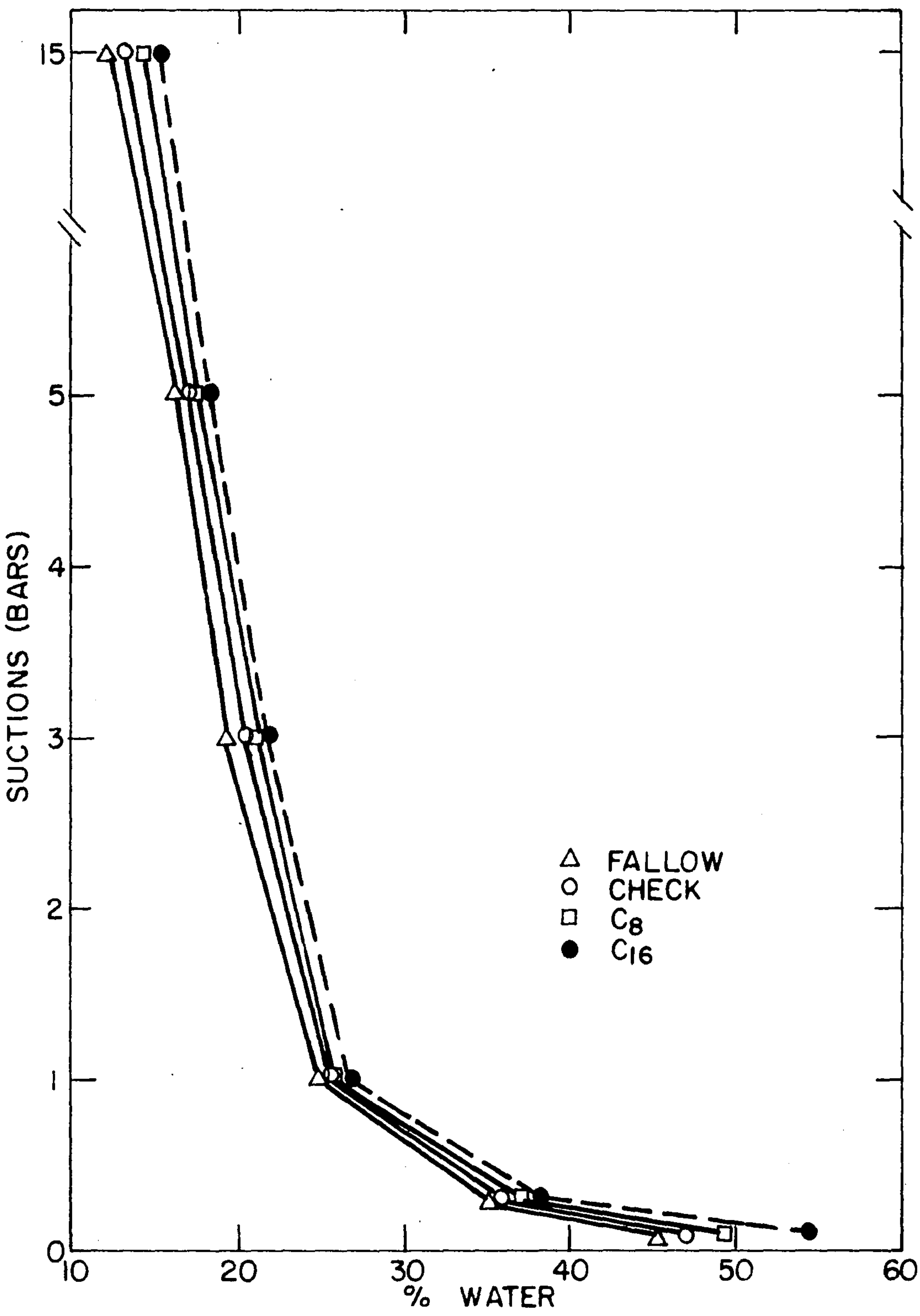
Peele (89) and Klute and Jacob (61) reported decrease in bulk density by the incorporation of organic matter. Bertramson and Rhoades (11) found no appreciable effect on volume weight (bulk density) by application of manure in a heavy soil. Cole (28) reported decrease in volume weight by plowing. Strickling (119) reported no correlation between volume weight and aggregate stability.

It may be concluded that continuous application of organic residues have an influence in reducing the bulk density of soil. The effect is clearly shown, particularly at higher levels of application.

6. Soil moisture retention The percent of water retention by weight under different suctions for the treatments F, Ck, C_8 and C_{16} are shown in Figure 21. All the treatments indicate the effect of residue application in increasing retention of moisture. While fallow plot has the lowest percentage of water retention under all suctions, C_{16} has the highest. The curves of Ck, and C_8 falls in between the fallow and C_{16} treatments.

The average percentage of moisture for these treatments along with C_4, A_4, O_4, S_4 and G_4 are given in Table 15. The

Figure 21. The percent by weight of water retention under different suctions (bars) in F, Ck, C_8 and C_{16} treatments.



SUCTIONS (BARS)
15
5
4
3
2
1
0
10
20
30
40
50
60
% WATER
FALLOW
CHECK
C8
C16

Table 15. Water retention under different suctions

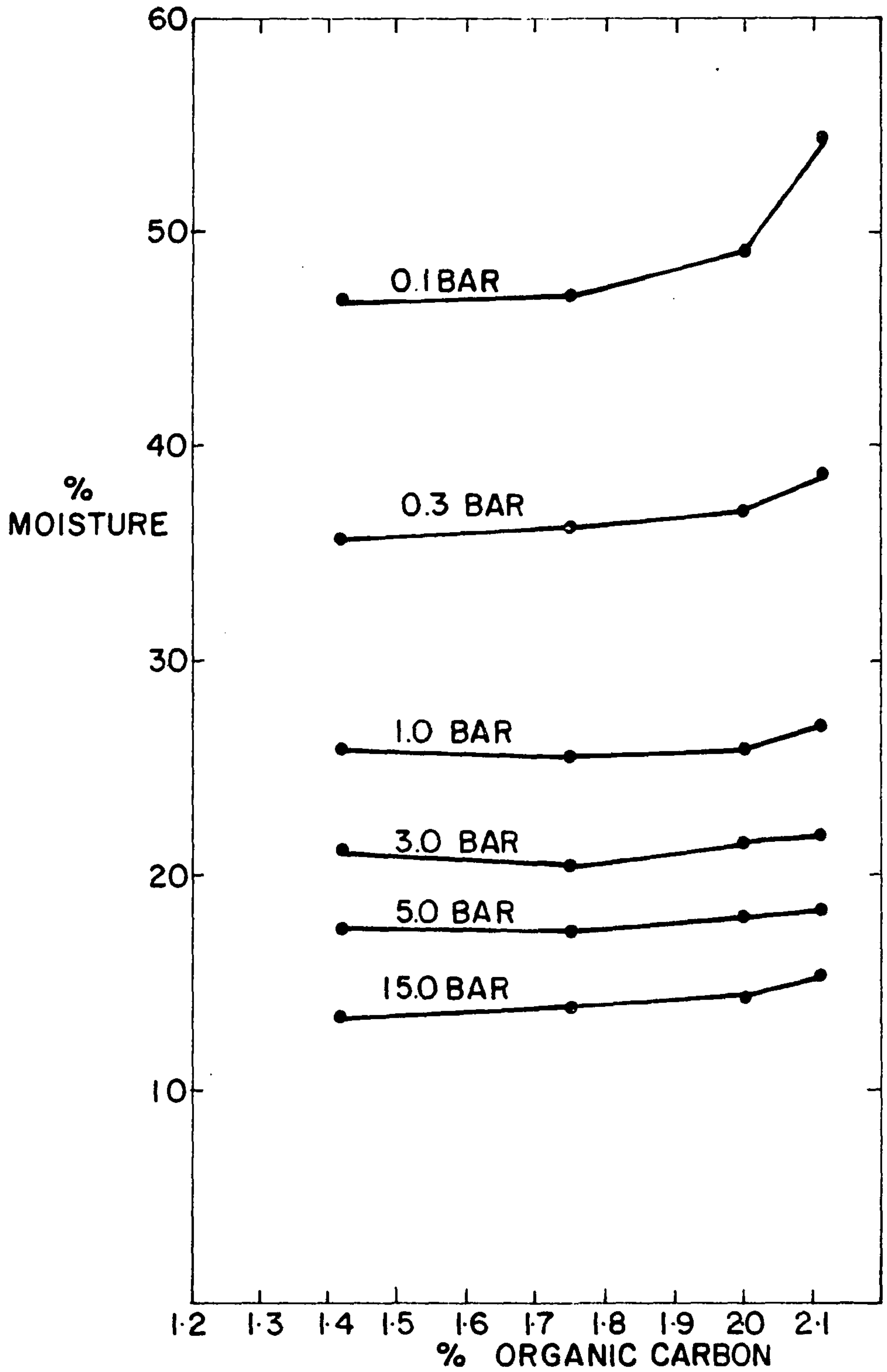
Tmt.	% Water retention at bars					
	15.0	5.0	3.0	1.0	0.3	0.1
F	12.58	16.46	19.55	24.93	35.16	45.30
Ck	13.33	17.45	21.20	25.97	35.72	46.88
C_8	14.30	18.09	21.46	25.88	36.94	49.19
C_4	13.80	17.32	20.38	25.61	36.27	47.09
A_4	13.72	17.33	20.88	25.28	36.33	47.16
S_4	13.81	17.33	20.49	25.49	36.66	47.43
O_4	13.79	17.38	21.23	25.40	36.33	48.54
G_4	13.64	17.78	21.28	25.82	36.57	48.68
C_{16}	15.39	18.30	21.89	26.93	38.64	54.36

data indicate that equal quantities of organic residues applied, retain equal water under all suctions.

The average percentage of moisture in relation to organic carbon content at different suctions are shown in Figure 22. Organic carbon shows the least influence at 15 bars and maximum influence at 0.1 bar.

When organic matter is added to soil, it does not appreciably increase the amount of available water (7). Russel (109) reported a slight increase in available water from addition of organic matter. Jamison (53) found for soils of southeastern United States that except for sandy soils greater

Figure 22. Relationship of organic carbon content to water retention under different suctions.


60
50
40
30
20
10
% MOISTURE
0.1 BAR
0.3 BAR
1.0 BAR
3.0 BAR
5.0 BAR
15.0 BAR
1·2
1·3
1·4
1·5
1·6
1·7
1·8
1·9
20
2·1
% ORGANIC CARBON

organic matter content did not increase the capacity of a soil to store available water.

Assuming that the wilting point at 15 bars and field capacity at 0.3 bar, the increase in available water from Ck to C_4 is only 0.08 percent. Similarly, the increase from C_4 to C_8 is 0.17 percent while it is 0.61 percent from C_8 to C_{16}. It is likely that even this increase may be partly due to undecomposed residues in C_8 and C_{16}.

From these data it can be concluded that although the water holding capacity is increased by application of organic residues, the increase in available water is negligible.

7. <u>Withstanding pressure of aggregates and the theory of aggregate formation</u> The percentage by weight of different aggregate sizes for the depths 0 to 3 and 3 to 6 inches are shown in Figures 15 and 16 for the treatments F, Ck, C_8 and A_8. The percent of aggregation as shown in Figure 15 and 16 indicates greater aggregation in surface (0 to 3 inches) soil. The same pattern is seen in all treatments in the organic matter experiment as well as in the rotation experiment plots, the data of which are shown in Tables 10(a and b) and 16. Considering Figure 15, it clearly indicates that while the percent of size group >3.0 mm. is increasing in both depths, the greatest difference in the percent between depths is found in size >12 mm. indicating that most of the differences found in the size groups of <2.0 mm. is caused by the depletion of size group >9.0 mm. in the surface soil. Hence,

Table 16. Soil aggregate size distribution by dry sieving (rotation and continuous meadow treatments)

Tmt.	% Size groups in mm.							
	<0.5	0.5-1	1-2	2-3	3-5	5-9	9-12	>12
COMM[a]	3.58	6.15	7.80	4.14	5.91	7.91	30.52	33.98
180-20-0	4.84	7.88	10.23	4.80	6.83	9.14	32.73	23.48
0-20-0	3.89	6.94	8.15	3.94	5.20	7.15	29.98	37.04
Cont. meadow	3.40	4.07	7.81	6.17	10.01	13.02	35.61	19.76

[a]Corn-oats-meadow-meadow rotation.

it is likely that the clod size group of >9.0 mm. give rise to the <2.0 mm. groups. In other words, it is the clods that give rise to aggregates of <2.0 mm. groups when they are broken down by cultural operations under field conditions.

a. Concept of basic blocks On a perusal of Figures 15 and 16, it is seen that the percentage of the total soil in size group >9.0 mm. increases sharply in both depths under all treatments. This group constitutes over 45 percent of total mass in 0 to 3 inch and over 65 percent in 3 to 6 inch depth. The difference from the smaller size groups indicates that this fraction of the soil mass is a separate entity. Thus, the soil units >9.0 mm. are termed soil clods in the remaining sections of this chapter.

The clods >9.0 mm. were deleted and the percentage of occurrence of the different size groups were calculated on the basis that the aggregates >9.0 mm. equals 100. The percentage distribution of aggregates under sieve size for treatments F, Ck, A_4, A_8 and C.M. are shown in Figures 23, 24 and 25. It should be pointed out that in order to overcome the arbitrary nature of the sieve sizes, the percentage of aggregates under different sieve sizes have been shown in these figures. The curves show that the slopes of the lines between 1 and 2 mm. are all about the same except in C.M. even though their absolute values are quite different. Further, the curves show that about 20 percent by weight of the aggregates occur between 1.0 and 2.0 mm. sizes in all treatments except C.M. The

Figure 23. Relationship of percent soil aggregates under sieve size to different size sieves for check and A_8 treatments showing curves obtained by dry sieving for 0 to 3 and 3 to 6 inch depths, wet sieving for 0 to 6 inch depth and different size aggregates subjected to a pressure of 100 psi (the broken lines in the curves indicate the percentage aggregates under sieve size for 1.0 to 2.0 mm.).

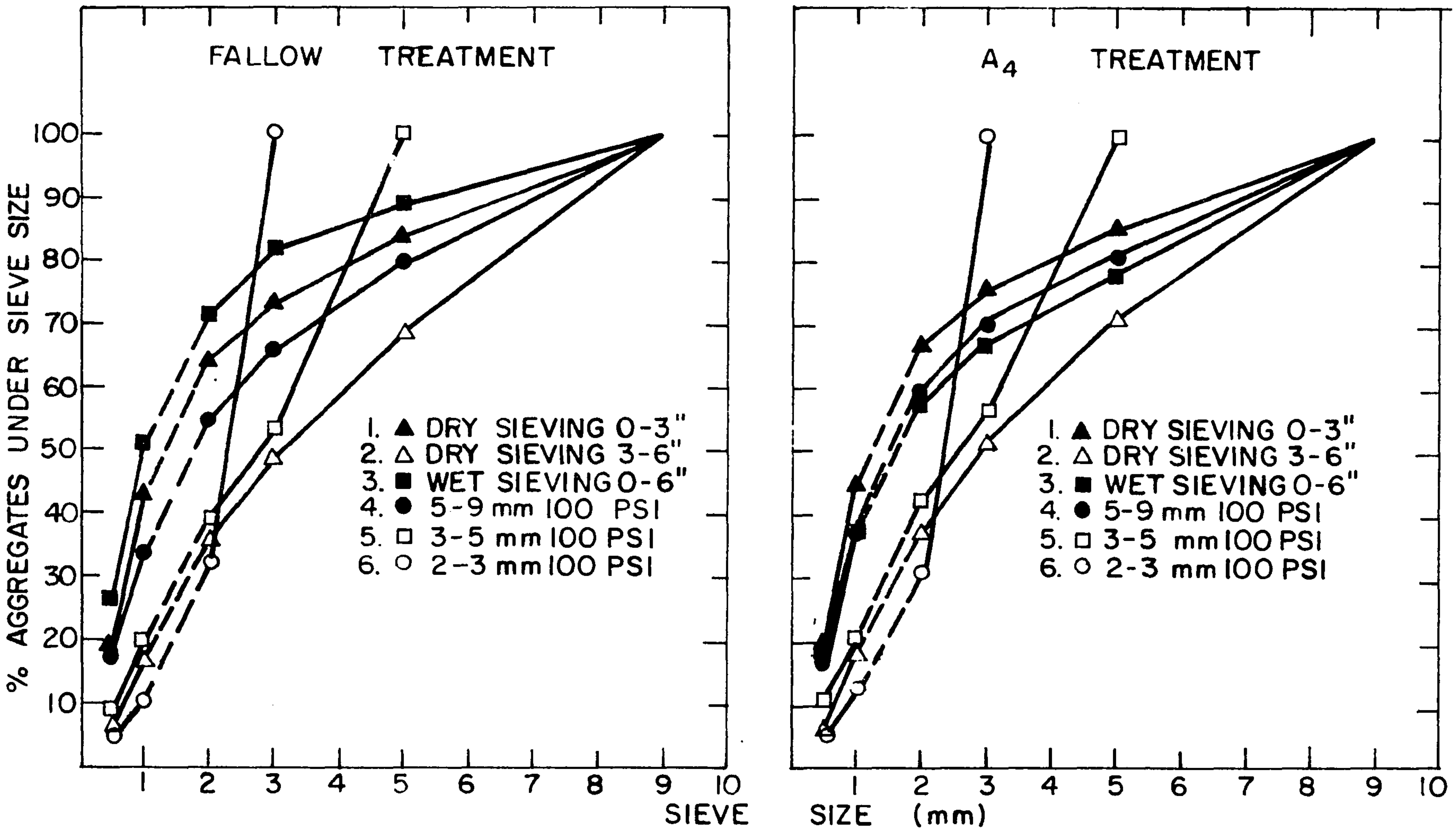

FALLOW TREATMENT
A4 TREATMENT
% AGGREGATES UNDER SIEVE SIZE
100
90
80
70
60
50
40
30
20
10
1 2 3 4 5 6 7 8 9 10
SIEVE SIZE (mm)
1. ▲ DRY SIEVING 0-3"
2. △ DRY SIEVING 3-6"
3. ■ WET SIEVING 0-6"
4. ● 5-9 mm 100 PSI
5. □ 3-5 mm 100 PSI
6. ○ 2-3 mm 100 PSI

Figure 24. Relationship of percent soil aggregates under sieve size to different size sieves for F and A_4 treatments showing curves obtained by dry sieving for 0 to 3 and 3 to 6 inch depths, wet sieving for 0 to 6 inch depth and different size aggregates subjected to a pressure of 100 psi. (The broken lines in the curves indicate the percentage aggregates under sieve size for 1.0 to 2.0 mm.).

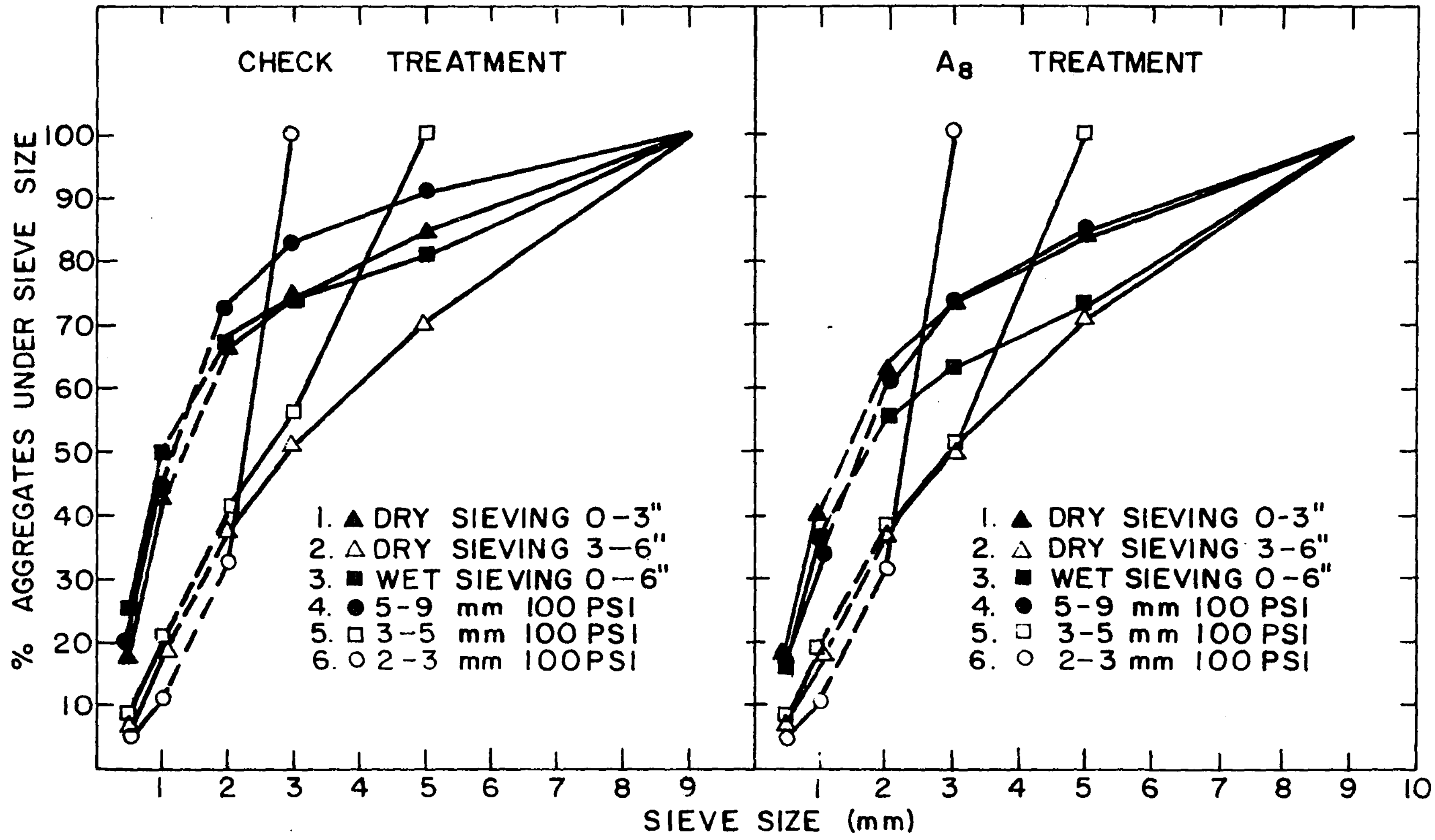
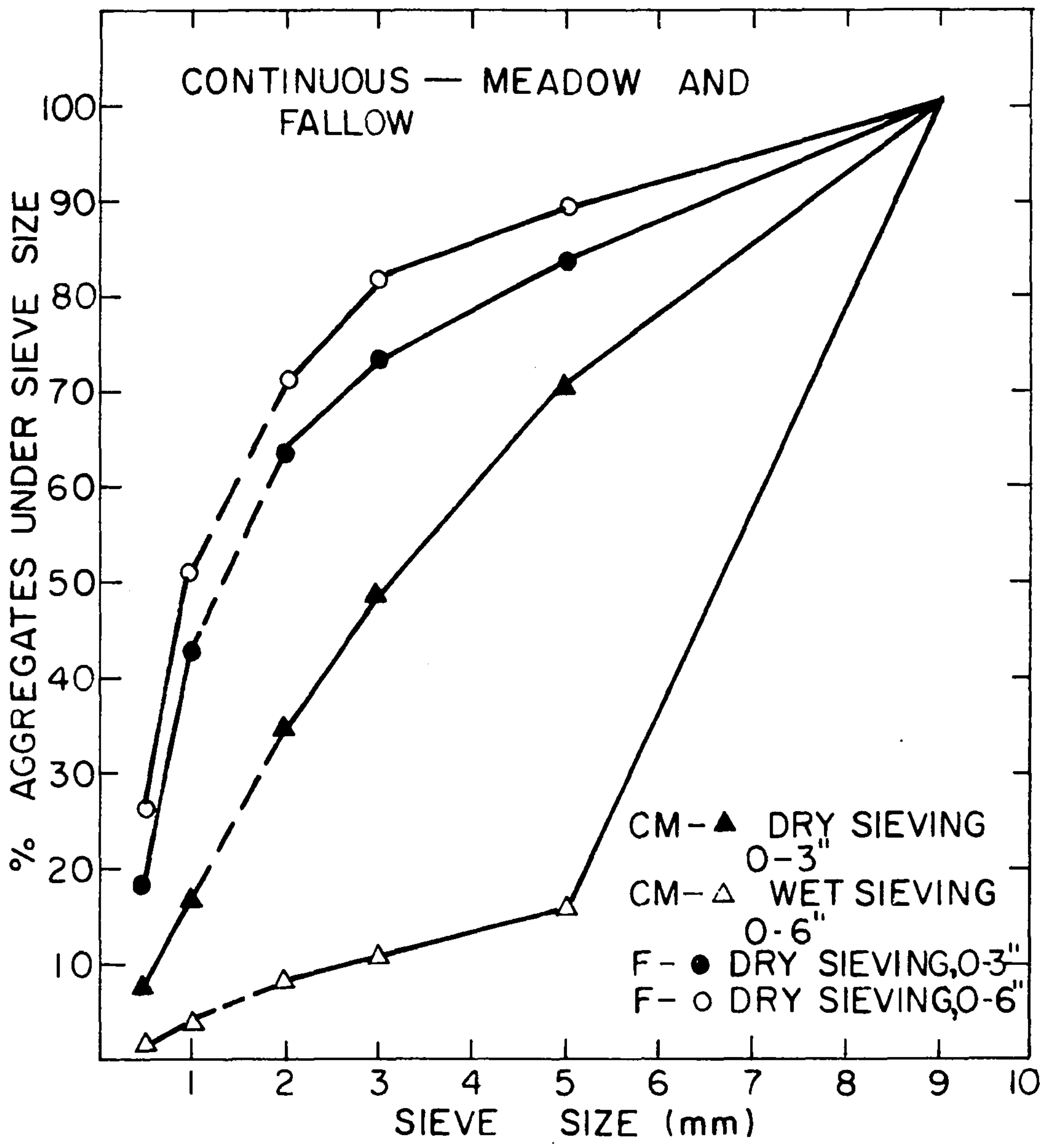

CHECK TREATMENT
A_8 TREATMENT
% AGGREGATES UNDER SIEVE SIZE
SIEVE SIZE (mm)
1. ▲ DRY SIEVING 0-3"
2. △ DRY SIEVING 3-6"
3. ■ WET SIEVING 0-6"
4. ● 5-9 mm 100 PSI
5. □ 3-5 mm 100 PSI
6. ○ 2-3 mm 100 PSI

Figure 25. Relationship of percent soil aggregates under sieve size to different size sieves for continuous meadow and fallow treatments showing curves obtained by dry sieving for 0 to 3 inch depth and wet sieving for 0 to 6 inch depth. (The broken lines in the curve indicate the percentage aggregates under sieve size for 1.0 to 2.0 mm.)



CONTINUOUS — MEADOW AND FALLOW
% AGGREGATES UNDER SIEVE SIZE
100
90
80
70
60
50
40
30
20
10
1 2 3 4 5 6 7 8 9 10
SIEVE SIZE (mm)
CM - ▲ DRY SIEVING 0-3"
CM - △ WET SIEVING 0-6"
F - ● DRY SIEVING,0-3"
F - ○ DRY SIEVING,0-6"

percent of 1.0 to 2.0 mm. group for all treatments is shown in Table 17. The data shows that the percent size group 1.0 to 2.0 mm. is near constant ranging from 20.4 to 23.4 percent except under extreme treatment conditions like C_{16} and C.M. This near constant percentage is also reflected in the similar slopes of the lines between 1.0 to 2.0 mm. sizes in Figures 23 and 24.

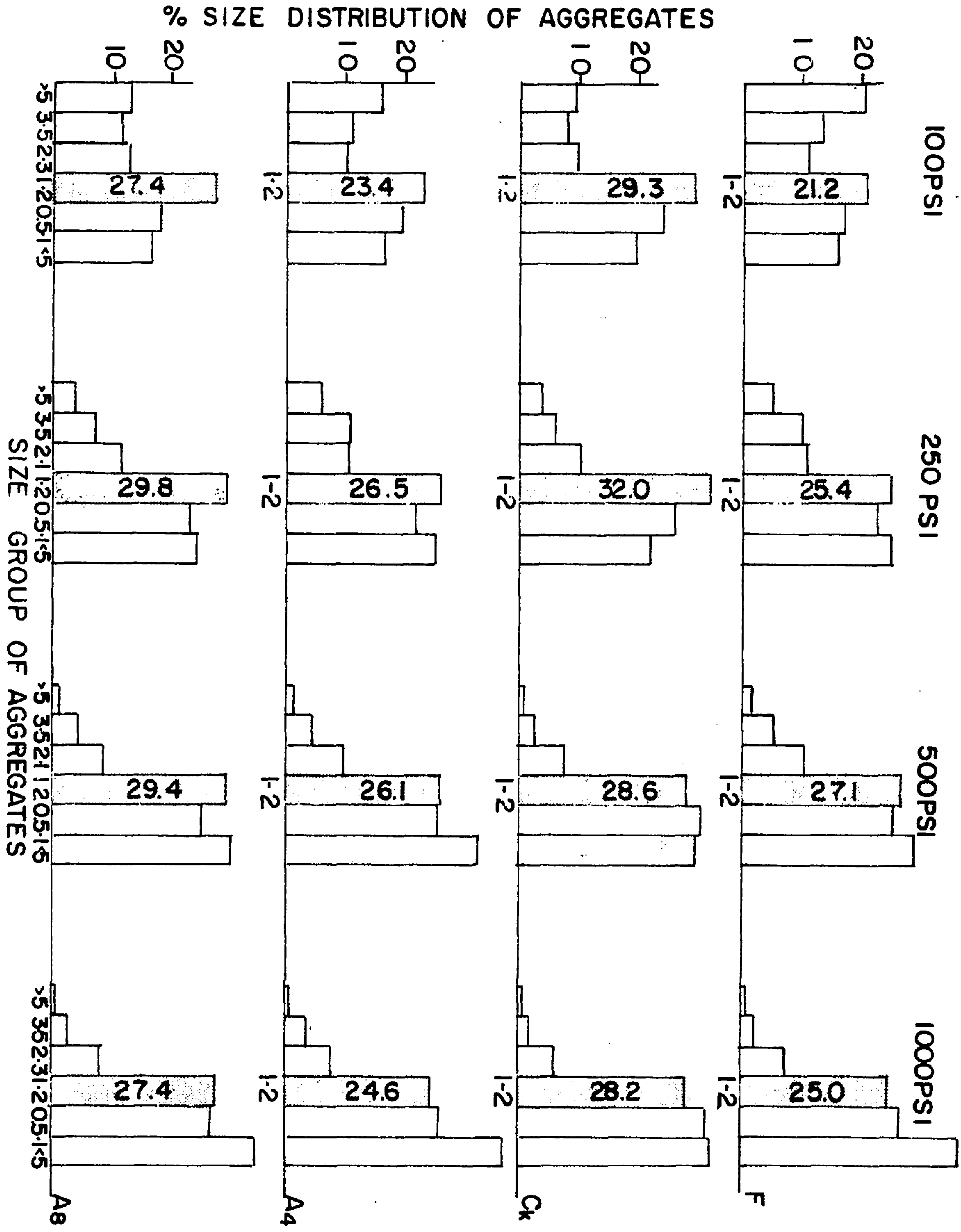
The constant percentage in the 1.0 to 2.0 mm. size group was tested further by breaking the aggregates of the size 2.0 to 3.0, 3.0 to 5.0 and 5.0 to 10.0 from the F, Ck, A_4 and A_8 treatments by subjection to a pressure of 100 pounds per square inch. The data obtained are shown in Figures 23 and 24. On examining the curves, it is seen that the 1.0 to 2.0 mm. group maintains its constant slope and percentage of about 20 in the three original size groups. Again it can be seen that when 5.0 to 10.0 mm. aggregates are subjected to varying pressures of 250, 500 and 1,000 pounds per square inch, the percentage of 1.0 to 2.0 mm. varies much less than the percentage for other groups (Figure 26).

The 1.0 to 2.0 mm. size group obtained by wet sieving when examined also indicates a rather constant percentage. The data are shown in Figures 23 and 24 and Table 11. In all the curves, the slope of the lines between 1.0 to 2.0 mm. aggregates (shown in broken lines) is about the same indicating the near constant percentage of this size group from both wet and dry sieving in the various treatments.

Table 17. Size distribution by weight of 1 to 2 mm. group as a percentage of the 0 to 9 mm. aggregate group totals

Treatments	1 to 2/0 to 9 mm. group x 100	
	0-3"	3-6"
F	21.3	18.5
Ck	22.6	18.9
C_1	22.6	19.1
C_2	22.6	19.4
C_{2-2}	21.8	18.9
C_4	22.5	19.5
$C_{\underline{8}}$	22.0	19.1
$C_{\underline{16}}$	22.2	19.0
C_8	21.2	18.9
A_1	22.1	18.6
A_2	20.8	19.8
A_4	22.0	19.1
A_8	22.3	20.2
S_4	21.7	19.8
O_4	22.4	19.2
G_4	22.8	19.1
C_{16}	20.4	17.2
Rot. 0-20-0	23.1	16.5
Rot. 180-20-0	23.4	24.9
COMM	22.0	17.7
Cont. meadow	17.6	14.2

Figure 26. The percent by weight of aggregate size groups obtained when 5.0 to 10.0 mm. aggregates from F, Ck, A_4 and A_8 treatments are subjected to a pressure of 100, 250, 500 and 1,000 pounds per square inch.


% SIZE DISTRIBUTION OF AGGREGATES
100PSI
250 PSI
500PSI
1000PSI
10-
20-
1-2
21.2
25.4
27.1
25.0
29.3
32.0
28.6
28.2
23.4
26.5
26.1
24.6
27.4
29.8
29.4
27.4
>5 3-5 2-3 1-2 0.5-1 <.5
SIZE GROUP OF AGGREGATES
F
Ck
A4
A8

Thus, from the above data it can be seen that the group 1.0 to 2.0 mm. constitutes a constant percentage of about 20 in both the wet and dry sieving. This indicates that these aggregates are strong and stable when compared to the larger aggregates. These aggregates may be called the basic blocks in view of their strength and stability.

The ability of the aggregate size groups in withstanding different crushing pressures is shown in Figure 27 and Table 18 for F, Ck, A_4 and A_8 treatments. The ability of smaller size aggregates in withstanding higher crushing pressure is indicated here. The percentage of aggregates that can withstand a pressure of 500 to 1,000 psi is negligible in 5.0 to 10.0 mm. aggregate group. However, the percentage of stable 1.0 to 2.0 mm. aggregates ranges from 67.6 to 79.2 under pressures from 500 to 100 psi indicating greater strength in case of 1.0 to 2.0 mm. aggregates. This strength is further increased in 0.5 to 1.0 mm. aggregate size. Thus, it is seen that smaller the aggregate, the more is their capacity to withstand pressure.

To confirm the greater strength of smaller aggregates the basic block group, energy of rupture was studied on aggregates of the 5.0 to 9.0 and 1.0 to 2.0 mm. groups. A total of 120 aggregates each from two check plots were selected and their energy of rupture studied by the method outlined by Rogowski (106). The results are given below in Table 19.

Figure 27. The ability of different size aggregates in withstanding crushing pressure of 100, 250, 500 and 1,000 pounds per square inch. (The curve represents the average of F, Ck, A_4 and A_8 treatments.)

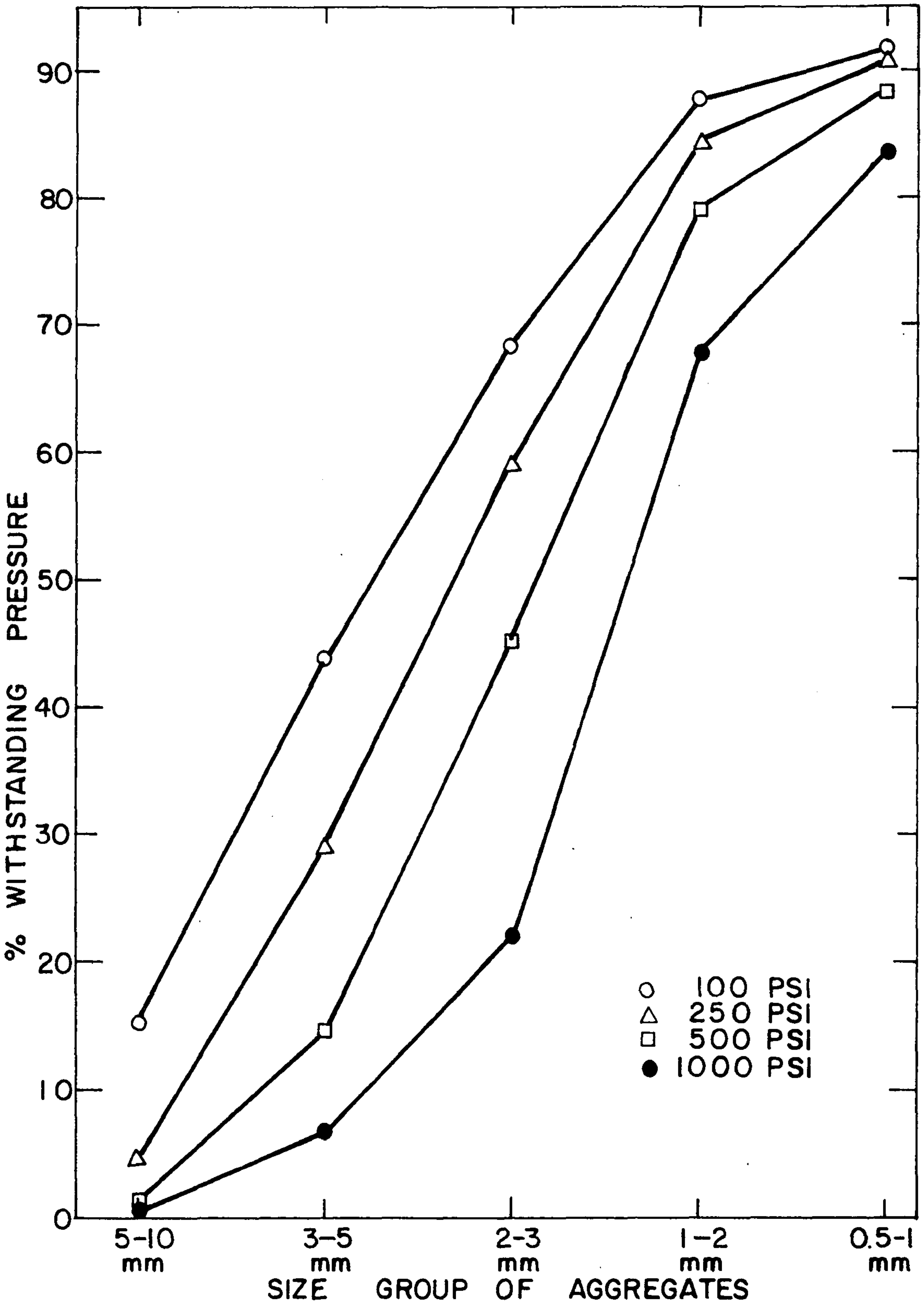

% WITHSTANDING PRESSURE
0
10
20
30
40
50
60
70
80
90
5-10 mm
3-5 mm
2-3 mm
1-2 mm
0.5-1 mm
SIZE GROUP OF AGGREGATES
100 PSI
250 PSI
500 PSI
1000 PSI

Table 18. Percentage by weight of different size aggregates not broken by different rates of pressures (average of F, Ck, A_4 and A_8 treatments)

Size group	Pressure applied lbs/sq. inch			
	100	250	500	1,000
5.0-10.0	15.0	4.6	1.3	0.5
3.0- 5.0	43.7	29.0	14.5	6.7
2.0- 3.0	68.5	59.2	45.1	21.8
1.0- 2.0	87.5	84.3	79.2	67.6
0.5- 1.0	91.5	90.5	88.3	83.5

Table 19. Energy of rupture and standard error for 2 different size groups

Treatments		Energy of rupture	±SE
Plot No.	Size in mm.	x 10^4 ergs./cm.^{2}	
15	5.0-9.0	1.34	0.095
	1.0-2.0	10.09	0.768
52	5.0-9.0	1.43	0.097
	1.0-2.0	9.14	0.749

The data clearly shows that the 1.0 to 2.0 mm. aggregates are about 7 times stronger than the 5.0 to 9.0 mm. size and confirms the view explained in the previous paragraph.

Literature is available on the factors causing aggregation such as organic matter, microorganisms, cations, clay colloids, etc. Different views have been expressed on the mechanism of aggregate formation mainly concerning the binding together of primary soil particles in the formation of aggregates. These have been reviewed earlier. But the data available on the strength and stability of different size aggregates and their role in aggregate formation and deterioration is meager. Page (87) visualized that aggregates may be formed directly both from the clods by reduction in size and build from the lower size groups. The data discussed here indicate that the basic blocks may have a major role in maintaining a balance in the complex process of aggregate formation and deterioration.

Rogowski (106) observed that the shape of soil aggregates became more spherical as the aggregate size decreased. Large aggregates and clods are often quite irregular in shape. Because many forces act upon aggregates in the soil, it is likely that they develop toward a sphere where the surface energy is lowest per unit mass.

Soils in their dry state (at least) behave as brittle materials, containing cracks or microfractures (106). These cracks may be numerous and of varying lengths. During weathering (tillage, wetting and drying, etc.) the stress and consequent strain is probably greatest at the junction between the aggregate or clod protrusions and the main clod mass. Thus, breakage will probably occur along these junctions in such a way so that the broken products become more spherical than the original. Initial rupture during weathering is also likely along lines of greatest weakness (lines of largest or most numerous cracks). In this way, the lines of greatest weakness are removed resulting in smaller but stronger soil aggregates.

Thus, the aggregates of 1.0 to 2.0 mm. tend to be more strong and stable due to their shape, surface energy and removal of larger fractures.

In Figure 25, the wet sieving curves of F and C-M treatments indicate the extremes in aggregate stability; the fallow aggregates being most unstable and the C-M most stable. The wet sieving procedure represents a rather drastic destructive treatment. On the other hand, the dry sieving of field soils represents a balance between the destructive forces in the field (tillage, raindrop impact, etc.) and the processes of aggregate formation (biological activity, root pressures, etc.). The dry sieving curve for F (Figure 25) shows a slightly higher aggregate size distribution than the wet sieving curve. This indicates that the strength of the F aggregates is low and that the balance between the destructive and the formative forces in the field approaches that of wet sieving.

However, the aggregate size distribution in the field (dry sieving) is considerably greater than from wet sieving in the C-M treatment. In this treatment the balance between the destructive and formative forces creates a much better aggregate size distribution than in F.

In Figure 25 the size range from 1.0 to 2.0 mm. represents the slope of the initial part of the aggregate size distribution curve. Since the curves must terminate at 100 percent, the percent undersize at the 1.0 and 2.0 mm. size levels indicates much as to the shape of the entire curve. Thus, a determination of the percent undersize at the 1.0 and 2.0 mm. levels provides a good index of the stability of the aggregates in both wet and dry sieving. The position of the 1.0 to 2.0 mm. size fractions on the curves also demonstrates their key role in the formation and deterioration of aggregates.

b. <u>Process of formation and deterioration of aggregates</u> The possible formative and deteriorative process of aggregation may be visualized as follows:

When the three groups of 2.0 to 3.0, 3.0 to 5.0 and 5.0 to 10.0 mm. were subjected to a pressure of 100 psi (Figures 23 and 24 and Table 20) the 1.0 to 2.0 mm. size remained constant at about 20 percent. However, the groups <2.0 mm. accounted to 31.6 percent in 2.0 to 3.0 mm., 39.9 percent in 3.0 to 5.0 mm. and 62.3 percent in 5.0 to 10.0 mm. These figures indicate that the percentage of <2.0 mm. size increases

Table 20. Percentage by weight of aggregates obtained when subjected to a pressure of 100 pounds per square inch (average of F, Ck, A_4 and A_8 treatments)

Size groups pressed mm.	Size groups obtained mm. 1.0-2.0	0.5-1.0	<0.5	Total
2.0-3.0	20.6	6.3	4.7	31.6
3.0-5.0	20.0	11.1	8.8	39.9
5.0-10.0	25.3	19.7	17.3	62.3

with the increase in aggregate size. Similar percentages are likely to be obtained in the deteriorative process of aggregation caused by weathering, root pressure, tillage, etc. Again if one visualizes the formative process caused by organic matter, microorganisms, soil colloids, cations, etc., similar percentages of size groups are likely to come together. However, it is possible that the size groups of <2.0 mm. may vary depending upon the situations like movement of heavy equipment, flooding, etc., while maintaining the constant nature of 1.0 to 2.0 mm. aggregates to the extent possible.

c. Cyclic nature in aggregate formation Soil aggregation is a continuing process. While aggregates are being formed by the contribution of organic matter, microorganisms, cations, soil colloids, etc., the breakdown of aggregates are taking place due to cultivation, traffic, irrigation, weather and others under field conditions.

Although the above process is known for years, the cyclic nature of aggregate formation is not clearly understood. The constant percentage of 1.0 to 2.0 mm. aggregates as basic blocks explained before indicates the above possibility. The possible formative and deteriorative process of aggregation has been described in previous paragraphs. It may be visualized that while certain percentage of 1.0 to 2.0 mm. aggregates are used for the formation of bigger sizes, an equal amount is added to it in the destructive process. It is also likely that when a certain percentage of 1.0 to 2.0 mm. aggregates are being formed from the smaller size groups due to addition of organic matter, etc., an equal percentage is likely to be used for the formation of next bigger size. In short, it is comparable to the well-known carbon and nitrogen cycles.

The similar pattern of aggregate size distribution in all the plots of this experiment as well as in the rotation experiment as shown in Tables 10 and 16 indicates the above possibility. The effect of any added treatment will be mostly felt in the decline of size group 1.0 to 2.0 mm. as in meadow and C_{16} in the formative process. During deteriorative process, the group 1.0 to 2.0 mm. will attain its original percentage of about 20 as in F.

Thus, it may be concluded that in the aggregate formation of soils, the size group of 1.0 to 2.0 mm. plays a key role in aggregate formation. These aggregates are strong and stable and formed over a period of years. When the aggregates are broken down under cultural conditions these basic blocks may not be affected and will be used once again for the formation of bigger aggregates.

V. SUMMARY AND CONCLUSIONS

It is generally accepted that organic matter is essential to the maintenance of good physical conditions and a high level of soil fertility. However, what the exact nature of these organic matter effects are and how these changes are brought about are in many instances, questions yet to be answered.

Arable soils receive organic matter from the residues of the crops growing on them. Different forms of organic residues are added in well-farmed arable soils. For proper evaluation of their effects, the amount and kinds of organic matter used and length of time after treatment before measurements are considered important.

This study was made on an experiment initiated by Dr. W. V. Bartholomew in 1953 at the Soil Conservation Experimental Farm, Clarinda, Iowa, wherein systematic incorporation of plant residues have been made since that time under continuous corn culture.

Bulk soil samples from 0 to 6 inches and core samples for 0 to 3 and 3 to 6 inches were collected in 1965 for studying physical characteristics of soil. The bulk samples were passed through a rotary sieve and aggregates of different size groups obtained. For chemical studies, samples were collected from 0 to 6 and 6 to 12 inch depths. The organic matter build up in the soil was studied by determining the organic carbon content and the amount of undecomposed organic residues. The soil pH was studied to evaluate the effects of organic residues and the associated nitrogen application.

Corn yield for the years 1956 to 1965 and corn leaf analysis in 1965 were studied to evaluate the cumulative effects of residue application.

To evaluate the physical properties of soil, the following characteristics were studied.

1. Aggregate size distribution by dry sieving
2. Aggregate size distribution and stability by wet sieving
3. Stability of compressed aggregates
4. Aggregate rupture stress and strain
5. Soil bulk density
6. Soil moisture retention, and
7. Withstanding pressure of aggregates

On the basis of the results of this study, it is concluded that:

1. There was an increase of organic carbon in the 0 to 6 inch soil depth in relation to the amount of residue applied. The increased residue application had little effect in the 6 to 12 inch depth.

2. Equal amount of different kinds of residues and applied at different time intervals produced equal increases in organic carbon in 0 to 6 inch depth. The increase over the years is continuous.

3. Corn roots accounted for an equivalent of 0.5 ton residue application per acre per year.

4. The maximum level of organic matter amounted to 3.4 percent and further increase was very slow.

5. The quantity of undecomposed residues is more in higher levels of cornstalk and sawdust application.

6. Soil pH decreased both in 0 to 6 and 6 to 12 inch soil depth. The associated nitrogen application had greater influence in reducing soil pH than did the residue application treatments.

7. Equal quantities of different types of residues produced dissimilar pH due to their chemical composition and associated nitrogen application.

8. The decline in soil pH continued over the period of years.

9. Application of large quantities of crop residues and nitrogen over a period of years had no influence on the yield increase of corn; on the contrary, the cumulative effects of these treatments may have an adverse effect in reducing growth and yield.

10. Organic carbon had very little influence on the nutrient uptake by the young corn plants. It was influenced greatly by the associated nitrogen application and the resulting soil pH.

11. The size distribution by weight of soil aggregates between the sizes 0.5 to 12.0 mm. was affected differently

with increased rates of residue application. In case of alfalfa hay, the aggregation was related to the amount of residue applied; but in cornstalks, the aggregation reduced after the 2 ton per acre per year application. Residue application at higher levels (8 and 16 tons) increased the stability of aggregates.

12. When natural aggregates were subjected to moisture, pressure, grinding and incubation treatments, their water stability increased considerably. The effect of organic matter in increasing aggregate stability was more visible when subjected to moisture and pressure treatments.

13. The organic carbon content had little influence on the strength of individual soil aggregates. The smaller the size of aggregates, the greater was the strength.

14. Organic residues decreased the soil bulk density. Significant differences from the check is seen only at higher level (16 tons) application.

15. Additions of organic residues increased water holding capacity at all suctions, but the increase in available water was negligible.

A theory on soil aggregate formation was postulated on the concept of basic blocks. Aggregate size groups of 1 to 2 mm. constituting about 20 percent by weight formed the basic blocks. This group was stronger than bigger aggregates and was more stable. Based on the basic block concept, possible formation of bigger aggregates and cyclic nature of aggregate formation was described.

VI. BIBLIOGRAPHY

1. Alderfer, R. B. Physical condition of the soil affects fertilizer utilization. Better Crops with Plant Food 38, No. 10: 24, 44-45. 1954.

2. Alderfer, R. B. and Merkle, F. G. The measurement of structural stability and permeability and the influence of soil treatments upon those properties. Soil Sci. 51: 201-211. 1941.

3. Allmaras, R. R., Burwell, R. E., Voorhees, W. B., and Larson, W. E. Aggregate size distribution in the row zones of tillage experiments. Soil Sci. Soc. Am. Proc. 29: 645-650. 1965.

4. Anderson, W. B. and Kemper, W. D. Corn growth as affected by aggregate stability, soil temperature and soil moisture. Agron. J. 56: 453-456. 1964.

5. Audus, L. J. Plant growth substances. New York, New York, Interscience Publishers. 1953.

6. Baver, L. D. Factors contributing to the genesis of soil microstructure. Am. Soil Survey Assoc. Bull. 16: 55-56. 1935.

7. Baver, L. D. Soil physics. 3rd ed. New York, New York, John Wiley and Sons, Inc. 1965.

8. Baver, L. D. and Farnsworth, R. B. Soil structure effects in the growth of sugar beets. Soil Sci. Soc. Am. Proc. 5: 45-48. 1940.

9. Beacher, B. F. and Strickling, E. Effect of puddling on water stability and bulk density of aggregates of certain Maryland soils. Soil Sci. 80: 363-373. 1955.

10. Bear, F. E. and Prince, A. L. Organic matter in New Jersey soils. New Jersey Agr. Expt. Sta. Bull. 757. 1951.

11. Bertramson, B. R. and Rhoades, H. F. The effects of cropping and manure applications on some physical properties of a heavy soil in eastern Nebraska. Soil Sci. Soc. Am. Proc. 3: 32-36. 1938.

12. Black, C. A. Soil-plant relationships. New York, New York, John Wiley and Sons, Inc. 1960.

13. Boller, C. A. and Stephenson, R. E. Some effects of mulches on soil properties. Am. Soc. Hort. Sci. Proc. 48: 37-39. 1946.

14. Bonner, James. The role of toxic substances in the interactions of higher plants. Bot. Rev. 16: 51-65. 1950.

15. Bottomley, W. B. The significance of certain food substances for plant growth. Ann. Bot. 28: 531-540. 1914.

16. Bradfield, Richard. The value and limitations of calcium in soil structure. Am. Soil Survey Assoc. Bull. 17: 31-32. 1936.

17. Bremner, J. M. A review of recent work on soil organic matter. Part I. Jour. Soil Sci. 2: 67-82. 1951.

18. Bremner, J. M. A review of recent work on soil organic matter. Part II. Jour. Soil Sci. 5: 214-232. 1954.

19. Broadbent, F. E. The soil organic fraction. Advan. Agron. 5: 153-183. 1953.

20. Broadbent, F. E. Some factors affecting nitrogen transformation and organic matter decomposition in soils. Unpublished Ph.D. thesis. Ames, Iowa, Library, Iowa State University of Science and Technology. 1948.

21. Broadbent, F. E. and Bartholomew, W. V. The effect of quantity of plant material added to soil on its rate of decomposition. Soil Sci. Soc. Am. Proc. 13: 271-274. 1949.

22. Brooks, R. H., Bower, C. A. and Reeves, R. C. The effect of various exchangeable cations upon the physical condition of soils. Soil Sci. Soc. Am. Proc. 20: 325-327. 1956.

23. Browning, G. M. Changes in erodibility of soils brought about by the application of organic matter. Soil Sci. Soc. Am. Proc. 2: 85-96. 1937.

24. Browning, G. M. and Milam, F. M. Rate of application of organic matter in relation to soil aggregation. Soil Sci. Soc. Am. Proc. 6: 96-97. 1941.

25. Chepil, W. S. A compact rotary sieve and the importance of dry sieving in physical soil analysis. Soil Sci. Soc. Am. Proc. 26: 4-6. 1962.

26. Chepil, W. S. Field structure of cultivated soils with special reference to erodibility by wind. Soil Sci. Soc. Am. Proc. 17: 185-190. 1953.

27. Clark, N. A. and Roller, E. M. The stimulation of lemma major by organic matter under sterile and non-sterile conditions. Soil Sci. 31: 299-309. 1931.

28. Cole, R. C. Soil macrostructure as affected by cultural treatments. Hilgardia 12: 429-472. 1939.

29. DeBoodt, M. and DeLeenheer, L. The practical measuring of the pore sizes with respect to the texture of soil. Int. Cong. Soil Sci. Leopoldville, 1954, Trans. 2: 104-110. 1954.

30. DeBoodt, M., DeLeenheer, L. and Kirkham, D. Soil stability indexes and crop growth. Soil Sci. 91: 138-146. 1961.

31. DeBoodt, M., Englehorn, A. J. and Kirkham, D. Fall vs. spring plowing and soil physical conditions in a rotation experiment. Agron. J. 45: 257-261. 1953.

32. Demolon, A. and Henin, S. Recherches sur la structure des limons et la synthese des aggregates. Soil Research 3: 1-9. 1932.

33. Dodge, D. A. and Jones, H. E. Effect of long time fertility treatments on the nitrogen and carbon content of prairie soils. J. Am. Soc. Agron. 40: 778-785. 1948.

34. Dutt, A. K. Puddling and other treatments in relation to soil structure and crop growth. Jour. Am. Soc. Agron. 40: 324-330. 1948.

35. Elson, J. and Lutz, J. F. Factors affecting aggregation of Cecil soils and effect of aggregation on runoff and erosion. Soil Sci. 50: 265-275. 1940.

36. Emerson, W. W. The structure of soil crumbs. J. Soil Sci. 10: 235-244. 1959.

37. Evans, Elfed and Gottlieb, David. Gliotoxin in soils. Soil Sci. 80: 295-301. 1955.

38. Flaig, W. Lectures on soil organic matter. Mimeographed. Ames, Iowa, Department of Agronomy, Iowa State University of Science and Technology. 1959.

39. Frederick, L. R. and Murphy, J. R. Laboratory manual for soil fertility students. Mimeographed. Ames, Iowa, Agronomy Section, Iowa State University of Science and Technology. 1965.

40. Gardner, W. R. Representation of soil aggregate-size distribution by a logarithmic-normal distribution. Soil Sci. Soc. Am. Proc. 20: 151-153. 1956.

41. Geltzer, F. Y. A Russian view of humus. Soil and Fertilizer 7: 119-121. 1944.

42. Giddens, J., Perkins, F. H. and Collins, W. O. Can soil organic matter be accumulated? Better Crops with Plant Food 35, No. 4: 25-26, 42-43. 1951.

43. Gish, R. E. and Browning, G. M. Factors affecting stability of soil aggregates. Soil Sci. Soc. Am. Proc. 13: 51-55. 1948.

44. Grunes, D. L. Effect of nitrogen on the availability of soil and fertilizer phosphorus to plants. Advan. Agron. 11: 369-396. 1959.

45. Hagin, J. Influence of soil aggregation on plant growth. Soil Sci. 74: 471-478. 1952.

46. Haise, H. R., Jensen, L. R. and Alessi, J. The effect of synthetic soil conditioners on soil structure and production of sugar beets. Soil Sci. Soc. Am. Proc. 19: 17-19. 1955.

47. Havis, L. Aggregation of an orchard and a vegetable soil under different cultural treatments. Ohio Agri. Expt. Sta. Bull. 640. 1943.

48. Hely, F. W., Bonnier, Charles and Manil, Paul. Investigations concerning nodulation and growth of lucerne seedlings in a loess soil artificially aggregated to various levels. Plant and Soil 5: 121-131. 1954.

49. Holtz, H. F. and Vandecaveye, S. C. Organic residues and nitrogen fertilizers in relation to the productivity and humus content of Palouse silt loam. Soil Sci. 45: 143-163. 1938.

50. Hubbel, D. S. and Staten, Glen. Studies on soil structure. New Mexico Agri. Expt. Sta. Tech. Bull. 363. 1951.

51. Hutchinson, H. B. and Clayton, J. On the decomposition of cellulose by an aerobic organism. Jour. Agr. Sci. 9: 143-173. 1919.

52. Hutchinson, H. B. and Richards, E. H. Artificial farm yard manure. Great Britain Min. Agr. Jour. 28: 398-411. 1921.

53. Jamison, V. C. Changes in air-water relationships due to structural improvement of soils. Soil Sci. 76: 143-151. 1953.

54. Jenny, Hans. Soil fertility losses under Missouri conditions. Missouri Agri. Expt. Sta. Bull. 324. 1933.

55. Jenny, Hans. A study of influence of climate upon the nitrogen and organic matter content of soil. Missouri Agri. Expt. Sta. Bull. 152. 1930.

56. Jensen, H. L. On the influence of the carbon: nitrogen ratios of organic material on the mineralization of nitrogen. Jour. Agr. Sci. 19: 71-82. 1929.

57. Johnston, J. R., Browning, G. M. and Russel, M. B. The effect of cropping practices on aggregation, organic matter content, and loss of soil and water in the marshall silt loam. Soil Sci. Soc. Am. Proc. 7: 105-107. 1942.

58. Keen, B. A. Experimental methods for the study of soil cultivation. Empire J. Exp. Agr. 1: 97-102. 1933.

59. Kemper, W. D. and Chepil, W. S. Size distribution of aggregates. In Black, C. A., editor. Methods of Soil Analysis. Part I. pp. 499-509. Madison, Wisconsin, American Society of Agronomy. 1965.

60. Kemper, W. D. and Koch, E. J. Aggregate stability of soils from the western portions of the United States and Canada. (To be published as a U.S. Department of Agriculture Technical Bulletin ca. 1965).

61. Klute, A. and Jacob, W. C. Physical properties of sassafras silt loam as affected by long-term additions of organic matter. Soil Sci. Soc. Am. Proc. 14: 24-28. 1949.

62. Kolodny, L. and Neal, O. R. The use of micro-aggregation or dispersion measurement for following changes in soil structure. Soil Sci. Soc. Am. Proc. 6: 91-95. 1941.

63. Kroth, E. M. and Page, J. B. Aggregate formation in soils with special reference to cementing substances. Soil Sci. Soc. Am. Proc. 11: 27-34. 1945.

64. Larson, W. E. Organic matter experiment on Marshall silt loam. Unpublished data. Ames, Iowa, Dept. of Agronomy, Iowa State University of Science and Technology. 1965.

65. Latif, A. The influence of residue management on some properties of the exterior and interior portions of aggregates of Marshall silty clay loam. Unpublished M.S. thesis. Ames, Iowa, Library, Iowa State University of Science and Technology. 1966.

66. Laws, W. D. Water-soluble silicate application to a calcareous clay soil and effect on soil properties and nutrient uptake by plants. Soil Sci. Soc. Am. Proc. 15: 89-92. 1951.

67. Lutz, J. F. The relation of free iron in the soil to aggregation. Soil Sci. Soc. Am. Proc. 1: 43-45. 1936.

68. Martin, J. P. The effect of compost and compost materials upon the aggregation of the silt and clay particles of Collington sandy loam. Soil Sci. Soc. Am. Proc. 7: 218-222. 1942.

69. Martin, J. P. Microorganisms and soil aggregation. I. Origin and nature of some of the aggregating substances. Soil Sci. 59: 163-174. 1945.

70. Martin, J. P. and Waksman, S. A. Influence of microorganisms in soil aggregation and erosion. Soil Sci. 50: 29-47. 1940.

71. Martin, W. P., Taylor, G. S., Engibous, J. C. and Burnett, E. Soil and crop responses from field applications of soil conditioners. Soil Sci. 73: 455-471. 1952.

72. Martinson, D. C. and Olmstead, L. B. Crushing strength of aggregated soil materials. Soil Sci. Soc. Am. Proc. 14: 34-38. 1949.

73. Mazurak, A. D. Effect of Gaseous phase on water-stable synthetic aggregates. Soil Sci. 69: 135-148. 1950.

74. McCalla, T. M. The biology of soil structure. Jour. Soil and Water Conservation 1: 71-75. 1946.

75. McCalla, T. M. Influence of microorganisms and some organic substances on soil structure. Soil Sci. 59: 287-297. 1945.

76. McCalla, T. M. Influence of some microbial groups on stabilizing soil structure against falling water drops. Soil Sci. Soc. Am. Proc. 11: 260-263. 1945.

77. McCalla, T. M., Guenzi, W. D. and Norstadt, F. A. Microbial studies of phytotoxic substances in the stubble-mulch system. Zeitschrift für Allg. Mikrobiologie 3.3: 202-210. 1963.

78. McHenry, J. R. Mechanics in the formation of water-stable soil aggregates. Unpublished Ph.D. thesis. Ames, Iowa, Library, Iowa State University of Science and Technology. 1944.

79. McHenry, J. R. and Russel, M. B. Elementary mechanics of aggregation of puddled materials. Soil Sci. Soc. Am. Proc. 8: 71-78. 1943.

80. Mebius, L. T. A rapid method for the determination of organic carbon in soil. Anal. Chim. Acta 22: 120-124. 1960.

81. Millar, C. E., Turk, L. M. and Foth, H. D. Fundamentals of soil science. 3rd ed. New York, New York, John Wiley and Sons, Inc. 1958.

82. Miller, D. E. and Kemper, W. D. Water stability of aggregates of two soils as influenced by incorporation of alfalfa. Agron. J. 54: 494-496. 1962.

83. Morachan, Y. B. Long range experiment with special reference to permanent manurials at the Agricultural College, Coimbatore. Madras Agric. J. 50: 426-434. 1963.

84. Myers, H. E. Physical reactions between organic and inorganic colloids as related to aggregate formation. Soil Sci. 44: 331-357. 1937.

85. Myers, H. E. and McCalla, T. M. Changes in soil aggregation in relation to bacterial numbers, hydrogen-ion concentration and length of time soil was kept moist. Soil Sci. 51: 189-200. 1941.

86. Norman, A. G. Soil organic matter. I. Problems in the chemistry of soil organic matter. Soil Sci. Soc. Am. Proc. 7: 7-15. 1943.

87. Page, J. B. Principles of soil aggregation. Unpublished paper presented at Soil Microbiology Conference, Purdue University, June 21-24. Mimeographed. Madison, Wisconsin, Am. Soc. Agron. 1954.

88. Page, J. B. and Willard, C. J. Cropping systems and soil properties. Soil Sci. Soc. Am. Proc. 11: 81-88. 1946.

89. Peele, T. C. Microbial activity in relation to soil aggregation. Jour. Am. Soc. Agron. 32: 204-212. 1940.

90. Peele, T. C. and Beale, O. W. Effect of runoff and erosion of improved aggregation resulting from the stimulation of microbial activity. Soil Sci. Soc. Am. Proc. 6: 176-182. 1941.

91. Peele, T. C. and Beale, O. W. Influence of microbial activity upon aggregation and erodibility of lateritic soils. Soil Sci. Soc. Am. Proc. 5: 33-35. 1940.

92. Peerlcamp, P. K. The influence on soil structure of the "natural organic manuring" by roots and stubbles of crops. Trans. 4th Int. Cong. Soil Sci. 2: 50-54. 1950.

93. Peevy, W. J. and Norman, A. G. Influence of composition of plant materials on properties of the decomposed residues. Soil Sci. 65: 209-226. 1948.

94. Peterson, J. B. The role of clay minerals in the formation of soil structure. Soil Sci. 61: 247-256. 1946.

95. Pierre, W. H. Determination of equivalent acidity and basicity of fertilizers. Ind. and Eng. Chemistry, Anal. Edition 5: 229-234. 1933.

96. Pierre, W. H. The effect of nitrogenous fertilizers on soil acidity. Jour. Ind. and Eng. Chemistry 23: 1440. 1931.

97. Pierre, W. H. Nitrogenous fertilizers and soil acidity. I. Effect of various nitrogenous fertilizers on soil reaction. Jour. Amer. Soc. Agron. 20: 254-269. 1928.

98. Pinck, L. A., Allison, F. E. and Gaddy, V. L. The nitrogen requirements in the utilization of carbonaceous residues in soil. Jour. Amer. Soc. Agron. 38: 410-420. 1946.

99. Prince, A. L., Toth, S. J. and Blair, A. W. The chemical composition of soil from cultivated lands and from land abandoned to grass and weeds. Soil Sci. 46: 377-389. 1938.

100. Prince, A. L., Toth, S. J., Blair, A. W. and Bear, F. E. Forty year studies of nitrogen fertilizers. Soil Sci. 52: 247-261. 1941.

101. Puri, A. N., Asghar, A. G. and Dua, A. N. Physical characteristics of soils. VI. Influence of clay, exchangeable bases and hygroscopic moisture on soil cohesion. Soil Sci. 49: 239-249. 1940.

102. Quastel, J. H. Soil conditioners. Ann. Rev. Plant Physiol. 5: 75-92. 1954.

103. Retzer, J. L. and Russel, M. B. Differences in the aggregation of a prairie and gray-brown podsolic soil. Soil Sci. 52: 47-58. 1941.

104. Richards, L. A. Physical condition of water in soil. In Black, C. A., editor. Methods of soil analysis. Part I. pp. 128-151. Madison, Wisconsin, American Society of Agronomy. 1965.

105. Robinson, D. O. and Page, J. B. Soil aggregate stability. Soil Sci. Soc. Am. Proc. 15: 25-29. 1950.

106. Rogowski, A. S. Strength of soil aggregates. Unpublished Ph.D. thesis. Ames, Iowa, Library, Iowa State University of Science and Technology. 1964.

107. Rogowski, A. S. and Kirkham, D. Moisture, pressure and formation of water-stable soil aggregates. Soil Sci. Soc. Am. Proc. 26: 213-216. 1962.

108. Rogowski, A. S., Moldenhauer, W. C. and Kirkham, D. Energy of rupture of some soils. Unpublished paper presented before Div. S-6 Soil Sci. Soc. America at Columbus, Ohio, Nov. 2, 1965.

109. Russel, E. J. Soil conditions and plant growth. 8th ed. New York, New York, Longmans, Green and Co. 1950.

110. Russel, E. W. Soil structure. Great Britain Imp. Bur. Soil Sci. Tech. Comm. 37. 1938.

111. Rynasiewicz, J. Soil aggregation and onion yields. Soil Sci. 60: 387-395. 1945.

112. Schmidt, E. L. Soil microorganisms and plant growth substances. I. Historical. Soil Sci. 71: 129-140. 1951.

113. Sideri, D. I. On the formation of the structure of soil. II. Synthesis of aggregates: on the bonds uniting clay with sand and clay with humus. Soil Sci. 42: 461-480. 1936.

114. Slater, C. S. and Carleton, E. H. The effect of erosion on losses of soil organic matter. Soil Sci. Soc. Am. Proc. 3: 123-128. 1938.

115. Snedecor, G. W. Statistical methods. 5th ed. Ames, Iowa, The Iowa State University Press. 1962.

116. Sokolovsky, A. N. The problem of soil structure. Int. Soc. Soil Sci., Trans. First Commission, Soviet, Section, A, 1: 34-110. 1933.

117. Stallings, J. S. Soil aggregate formation. U.S. Dept. Agric. Soil Cons. Serv. Tech. Pub. 110: 23. 1952.

118. Stauffer, R. S. Effect of corn, soybeans, their residues and straw mulch on soil aggregation. Jour. Am. Soc. Agron. 38: 1010-1017. 1946.

119. Strickling, E. The effect of soybeans on volume-weight and water stability of soil aggregates: soil organic matter content and crop yield. Soil Sci. Soc. Am. Proc. 15: 30-34. 1950.

120. Swanson, C. L. W. and Jacobson, H. C. M. Influence of cultivation and weedkillers on soil structure and crop yields. Soil Sci. 69: 443-456. 1950.

121. Taylor, G. S. and Martin, W. P. Effect of soil aggregating chemicals on soils. Agric. Engineering 34: 550-554. 1953.

122. Taylor, H. M. and Gardner, H. R. Penetration of cotton seedling tap roots as influenced by bulk density, moisture content, and strength of soil. Soil Sci. 96: 153-156. 1963.

123. Tisdale, S. L. and Nelson, W. L. Soil fertility and fertilizers. 2nd ed. New York, New York, The Macmillan Company. 1966.

124. Tiulin, A. F. Considerations on the genesis of soil structure and on methods for its determination. Trans. 1st Comm. Int. Soc. Soil Sci. (Soviet Section), Vol. A: 111-132. 1933.

125. Van Bavel, C. H. M. and Schaller, F. W. Soil aggregation, organic matter and yields in a long term experiment as affected by crop management. Soil Sci. Soc. Am. Proc. 15: 399-404. 1950.

126. Vilensky, D. G. Studies on the process of soil aggregation (in Russian, English summary). Pedology 8: 28-37. 1940.

127. Vilensky, D. G. and Germonova, V. N. Experimental study of the problem of structure formation (in Russian, English summary). Pedology 2: 34-60. 1934.

128. Waksman, S. A. Influence of microorganisms upon the carbon-nitrogen ratio in the soil. Jour. Agr. Sci. 14: 555-562. 1924.

129. Weaver, J. E. Quantity of living plant materials in prairie soils in relation to run-off and erosion. Nebraska Univ. Cons. Dept. Bull. 8. 1935.

130. Weldon, T. A. and Hide, J. C. Some physical properties of soil organic matter and of sesquioxides associated with aggregation in soils. Soil Sci. 54: 343-351. 1942.

131. Whitney, Milton. Soil fertility. U.S. Dept. Agr. Farmers' Bull. 257. 1909.

132. Yoder, R. E. Significance of soil structure in relation to tilth problem. Soil Sci. Soc. Am. Proc. 2: 21-33. 1937.

133. Zakharov, S. A. Achievements of Russian science in morphology of soils. Russ. Pedolog. Investigations 2. 1927.

VII. ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation and thanks to Dr. W. E. Larson, for suggesting the problem, guidance in the early part of the work, comments, and for the thorough review of the thesis.

The author wishes to thank and acknowledge his indebtedness to Dr. W. H. Pierre and Dr. W. C. Moldenhauer for their guidance, suggestions and comments during the investigation of the problem.

The author wishes to thank Dr. F. F. Riecken for permitting work in his laboratory and Dr. R. R. Allmaras, Morris, Minnesota for the computation work.

The author wishes to thank the staff and student members of the Soil Management Section, particularly Mr. P. Peterson and Mr. Don Law for their valuable help both in the field and laboratory, and Mr. W. M. Edwards for computation work.

The author is highly obliged to the Rockefeller Foundation, New York, for the financial assistance offered for the entire graduate program at Ames, Iowa, and to the Government of Madras, India for granting necessary leave.

The author is also thankful to his wife and children for the inspiration offered by them during the period of the graduate program.

VIII. APPENDIX

Table 21. Analysis of variance of the undecomposed organic residues (0 to 6 inches) (for the data presented in Table 2)

Source of variation	d.f	S.S	M.S	Calculated F
Replications	3	0.0103	0.0034	
Treatments	15	0.1398	0.0093	4.48[a]
Error	45	0.0934	0.0021	

[a]Significant at 1 percent level, tabular F (0.01) = 2.48.

Table 22. Analysis of variance of the organic carbon content (0 to 6 inches) (for the data presented in Table 3)

Source of variation	d.f	S.S	M.S	Calculated F
Replications	3	0.36	0.12	
Treatments	15	1.97	0.13	7.2[a]
Error	45	0.79	0.018	

[a]Significant at 1 percent level, tabular F (0.01) = 2.48.

Table 23. Analysis of variance of the soil pH (0 to 6 inches) (for the data presented in Table 4)

Source of variation	d.f	S.S	M.S	Calculated F
Replications	3	0.92	0.30	
Treatments	15	2.20	0.14	6.1[a]
Error	45	1.03	0.023	

[a]Significance at 1 percent level, tabular F (0.01) = 2.48.

Table 24. Analysis of variance of corn yields indicating differences for testing adjusted treatment means (for the data presented in Table 5)

Type of analysis	Mean square	Error mean square	F
	<u>1956</u>		
1. Adjusted yield	113.	124.	0.92
2. Regression	55.	124.	0.45
3. Unadjusted stand	409.	243.	1.68
4. Unadjusted yield	114.	122.	0.93
	<u>1957</u>		
1. Adjusted yield	45.	38.	1.19
2. Regression	308.	38.	8.14
3. Unadjusted stand	149.	115.	1.29
4. Unadjusted yield	70.	44.	1.57
	<u>1958</u>		
1. Adjusted yield	41.	35.	1.18
2. Regression	1501.	35.	43.42
3. Unadjusted stand	210.	166.	1.26
4. Unadjusted yield	49.	69.	0.70

Table 24 (Continued).

Type of analysis	Mean square	Error mean square	F
	1959		
1. Adjusted yield	74.	67.	1.10
2. Regression	218.	67.	3.26
3. Unadjusted stand	204.	176.	1.16
4. Unadjusted yield	102.	71.	1.44
	1960		
1. Adjusted yield	70.	48.	1.46
2. Regression	897.	48.	18.87
3. Unadjusted stand	31.	69.	0.44
4. Unadjusted yield	70.	68.	1.04
	1961		
1. Adjusted yield	91.	42.	2.17[a]
2. Regression	3411.	42.	81.75
3. Unadjusted stand	335.	117.	2.87
4. Unadjusted yield	269.	122.	2.21

[a]Significance at 5 percent level tabular F (0.05) = 1.95.

Table 24 (Continued).

Type of analysis	Mean square	Error mean square	F
	1962		
1. Adjusted yield	86.	66.	1.30
2. Regression	2064.	66.	31.38
3. Unadjusted stand	181.	180.	1.00
4. Unadjusted yield	112.	113.	0.99
	1963		
1. Adjusted yield	48.	89.	0.54
2. Regression	3834.	89.	42.99
3. Unadjusted stand	74.	93.	0.80
4. Unadjusted yield	80.	178.	0.45
	1964		
1. Adjusted yield	120.	48.	2.49[b]
2. Regression	722.	48.	15.07
3. Unadjusted stand	105.	84.	1.26
4. Unadjusted yield	144.	64.	2.25

[b]Significance at 5 percent level tabular F (0.05) = 1.95.

Table 24 (Continued).

Type of analysis	Mean square	Error mean square	F
	1965		
1. Adjusted	283.	42.	3.66[c]
2. Regression	821.	42.	19.36
3. Unadjusted stand	47.	43.	1.10
4. Unadjusted yield	179.	60.	2.98

[c]Significance at 1 percent level tabular F (0.01) = 2.56.

Table 25(a). Analysis of variance of corn yield decline for the years 1963 to 1965 on treatments Ck, C_1, C_4, and C_8

Source of variation	d.f	S.S	M.S
	1963		
Regression	1	33.31	33.31
Deviations from regression	3	3.45	1.15
b = -0.91	Sb = 0.17	t = 5.39[a]	
	1964		
Regression	1	131.04	131.04
Deviations from regression	3	23.82	7.94
b = -1.82	Sb = 0.44	t = 4.14[a]	
	1965		
Regression	1	127.81	127.81
Deviations from regression	3	13.76	4.59
b = -1.79	Sb = 0.34	t = 5.27[a]	

[a]Significance at 5 percent level tabular t (0.05) = 3.18.

Table 25(b). Analysis of variance of corn yield decline for the years 1963 to 1965 on treatments Ck, A_1, A_2, A_4, and A_8

Source of variation	d.f	s.s	M.S.
1963			
Regression	1	3.36	3.36
Deviations from regression	3	23.11	7.70
b = -0.29	Sb = 0.5	t = 0.58	
1964			
Regression	1	15.5	15.5
Deviations from regression	3	0.53	0.18
b = -0.623	Sb = 0.058	t = 10.8[a]	
1965			
Regression	1	25.28	25.28
Deviations from regression	3	10.09	3.36
b = -0.795	Sb = 0.29	t = 2.74	

[a]Significance at 1 percent level tabular t (0.01) = 5.84.